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Vol. XI MAY, 1906 No. 3

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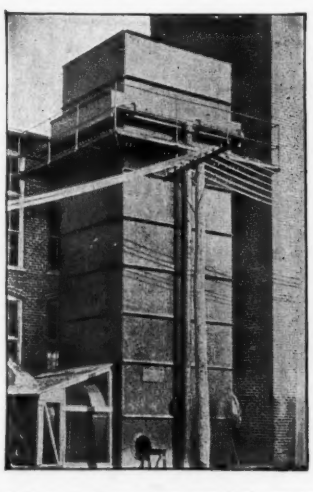

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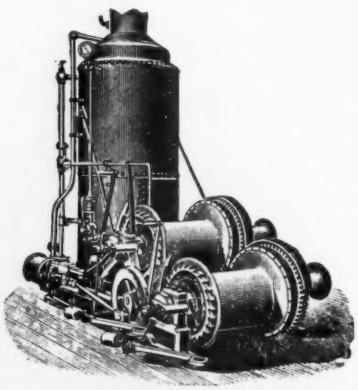

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MAY, 1906.

THE PRESSURE DROP THROUGH POPPET VALVES*

By Charles Edward Lucke, Ph. D.

1. All gas engines, most air compressors and ice machines and many steam engines, are fitted with poppet valves to control the fluid flow into or from the cylinders. These machines operate at widely different piston speeds and use fluids of widely differing densities with consequent varying velocities through the valves. The pressure drop for a given rate of flow, however, is dependent upon the fluid density, as well as its velocity, the form of opening, the form of approach and exit, the character of the flow, whether steady or intermittent, the inertia of the fluid and the friction of the passages. Although pressure drop through the valve is necessary to secure any flow whatever, such pressure drop is detrimental to the machine, causing, as it does, undesirable piston resistance and reduced volumetric efficiency of the cylinder. Pressure drop is reduced to a minimum in designing by allowing proper valve area to minimize fluid velocity, but too large a poppet valve for a given gas, or too large a lift for any given valve, introduces features of design equally as bad as too small a valve opening. The designer is thus forced to follow a middle course admitting some pressure drop through the valve, but not reducing fluid velocity so low as to require valves of excessively large diameter or excessively large lift. To design such a valve there should be available experimental data on the relation between pressure drop and the conditions tending to produce it, because it cannot be calculated on theoretic grounds, but on investigation it will be found that such information is unavailable.

2. The tests reported here had for their object the determination of some such experimental data on the relation between pressure drop through a poppet valve and the condition of flow, form of opening, etc., that give rise to the pressure drop observed. For any given velocity of flow the pressure drop will be greatest and most easily measured with a less dense fluid; for this reason atmospheric air was used. The gas engines in the experimental laboratories of Columbia University have poppet valves with flat and conical seats and are operated both automatically and by cams.

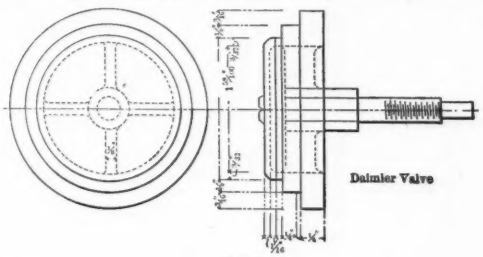


FIG 1.

These valves were so arranged for these tests as to allow measured quantities of air to flow both steadily and intermittently with various valve lifts and in both directions through the valves. The valve lift was measured by one special attachment for the tests made on the engines themselves and another for the tests on the detached valves with steady flow. The

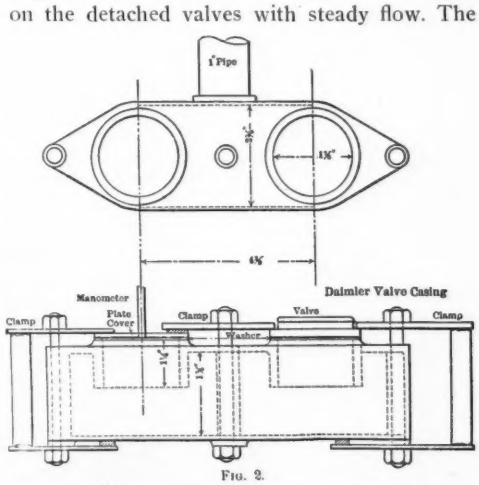


FIG. 2.

air was measured by a large Westinghouse meter and all pressure drops were measured in inches of water on a manometer. The experimental work was carried out as a thesis problem by two students of the graduating class, Mr. R. M. Strong and Mr. F. W. Hollman, to whom proper credit should be given.

*Abstract of paper read before the American Society of Mechanical Engineers.

3. The flat seat valve used was one from a Daimler engine, 1.58 inch inside diameter, arranged as shown in Fig. 1. For steady flow runs it was held open by small copper wedges carefully ground to size, three being used at a time, inserted at the outside edge of the valve so that the valve opening, which is measured by the inside edge of the valve, would not be restricted by the wedges. These wedges were of such size as to allow of four different

THE PRESSURE DROP THROUGH POPPET VALVES.

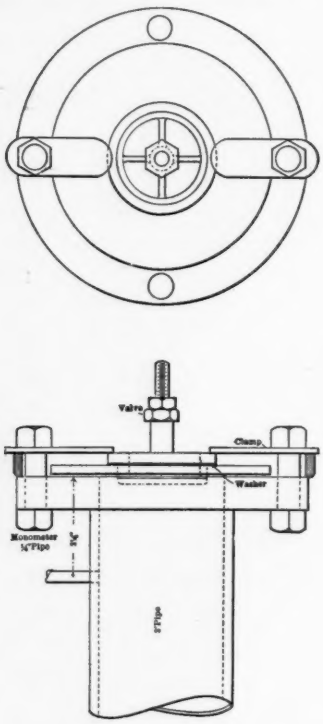


Fig. 3

lifts, 0.05, 0.10, 0.15 and 0.20 inches respectively. For each opening that the valves held rigidly between the valve and its seat, air was blown through the valve at varying rates with varying resulting pressure drops up to 30 inches of water. The arrangement of apparatus for carrying out this part of the work is shown in Figs. 2 and 3. Fig 2 is the arrangement used when the direction of flow was from the inside to out, and Fig. 3 is the arrangement of both directions as the valve fastening here is reversible.

4. The conical seat valves were furnished by a Nash gas engine and had diameters of 1½ and 2 inches. The small valve on the engine is used for the gas inlet and the larger for mixture inlet. The arrangement for steady flow runs are shown in Fig. 3.

5. Throughout this part of the work on steady flow of air, the air was measured before it reached the valve, and at a pressure higher than atmosphere, pressure drop occurring between meter line and atmosphere

THE PRESSURE DROP THROUGH POPPET VALVES.

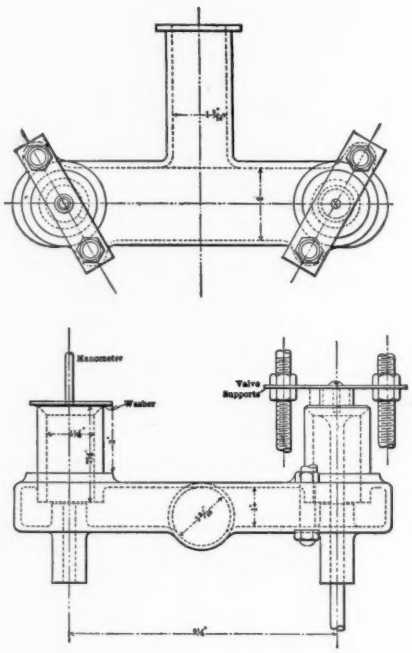


Fig. 4

and the manometer indicating the pressure drop, as shown in Fig. 5, as used. Flow of air from inside out is equivalent to exhaust stroke. For determining the readings of the meter and the pressure drop for the conical valve, when the flow of air was to be reversed, that is to say in the exhaust valve direction the entire valve and piping, as shown in Fig. 3, was enclosed in a chamber, and air was supplied to this chamber. The air then passed through the valve and out by a pipe which was used as a suction pipe on the engine.

6. The second series of runs was made with

the valves located on the engines as they ordinarily operate. For this purpose a Daimler engine was piped to a meter so that it caused a slight back pressure. The meter therefore measured the discharge of air after exhaust. The engine was then driven by a belt from a steam engine, and runs were made covering a range of speeds. The valve being automatic it was provided with stops so that the greatest openings corresponded to those for the

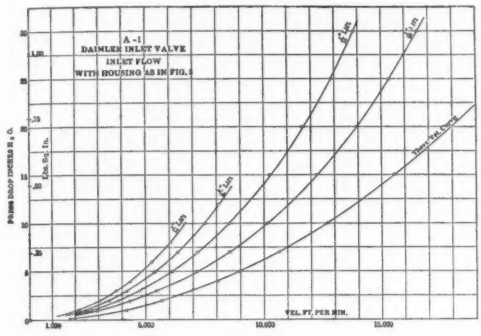


Fig. 5

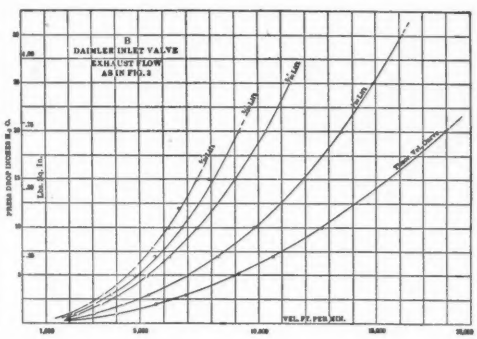


Fig. 7

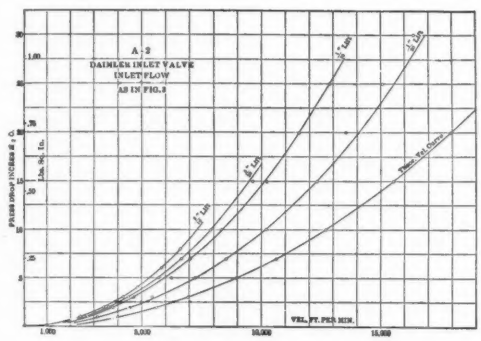


Fig. 6

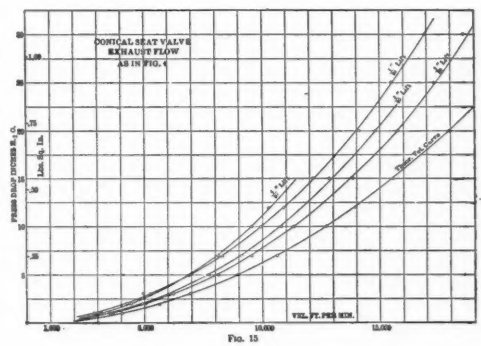


Fig. 8

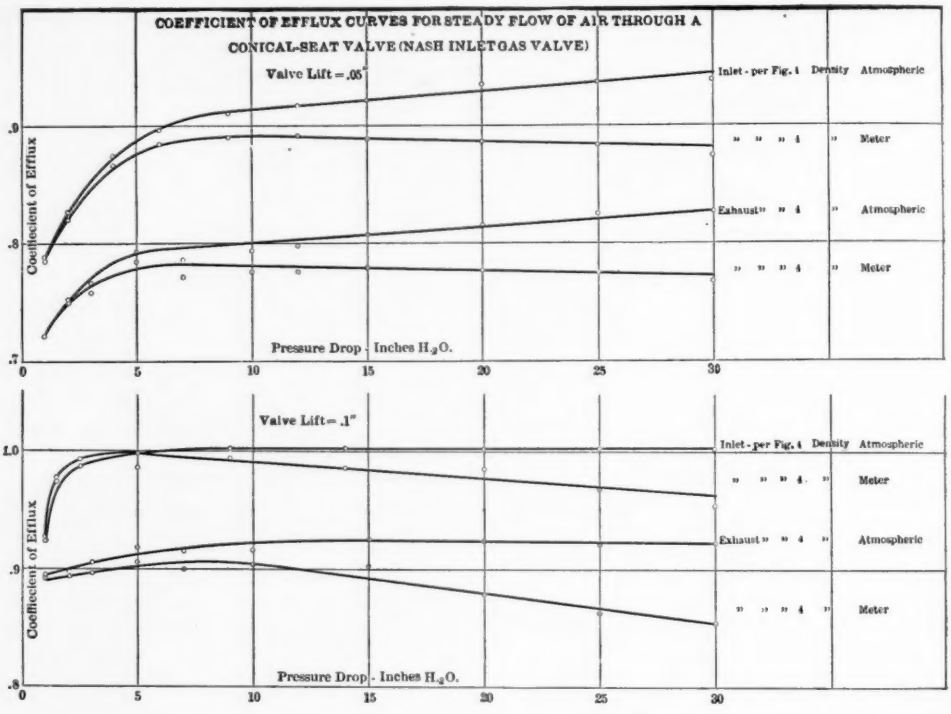
steady flow of runs, 0.05, 0.10, 0.15 and 0.20 inches. The actual lifts were drawn by an indicator, the piston rod being fastened to the valve stem. Pressure drops were measured by indicators on the cylinder carrying a 10-pound spring. After the readings for this valve were obtained the meter position was changed so that the engine would draw air through the meter before it reached the cylinder. In this case the pressure drop was from atmosphere to something below, while in the other case it was from something above atmosphere to something less, but still above atmosphere. As before, the engine was operated at a number of different speeds and the pressure drop through the exhaust valve was measured by the 10-pound spring indicator on the motor cylinder. This indicator card in fact gave the pressure drop through both valve courses on one diagram. The exhaust valve on this engine is mechanically opened by cams so that no stop could be used to adjust the openings to any desired limit. The actual lift of this valve was measured at any point of the stroke mechanically by causing a pencil fastened to the stem to draw a line on the indicator drum so that the lift is given for every point of the stroke and having differing actual piston speeds.

7. Intermittent runs were also made on the Nash engine, on which all valves are mechanically operated. Here the valve runs were measured as on the exhaust valves of the Daimler by attaching a pencil to the valve stem. Pressure drops were shown as before, on the 10-pound scale indicator card from the motor cylinder. There were two inlet valve determinations. First for the small valve used on the engine for the gas inlet, and second for the larger valve controlling the mixture admission

to the motor cylinder. These were not operated together. When the small one was being used the large one was held open and the air pipe plugged. When the large one was being used the small one was removed. In making the measurements on the exhaust valve the air for the engine, instead of being sent through the air pipe, was taken through the opening left by the removal of the small gas valve.

linear velocities of crank pin by the piston speed factors above. The Daimler engine had a bore of 3 15-16 inches and a stroke of 5 9-16 inches, giving a crank pin velocity of 145.6 feet per minute at 100 revolutions per minute.

9. The Nash engine had a bore of 6½ inches and a stroke of 10 inches, giving a crank pin velocity of 261.8 feet per minute at 100 revolutions per minute. Both engines had connecting rods five cranks long.


COEFFICIENT OF EFFLUX CURVES FOR STEADY FLOW OF AIR THROUGH A CONICAL-SEAT VALVE (NASH INLET GAS VALVE)
Valve Lift = .05"
Inlet - per Fig. 4 Density Atmospheric
" " " 4 " Meter
Exhaust " " 4 " Atmospheric
" " " 4 " Meter
Coefficient of Efflux
Pressure Drop - Inches H2O.
Valve Lift = .1"
Inlet - per Fig. 4 Density Atmospheric
" " " 4 " Meter
Exhaust " " 4 " Atmospheric
" " " 4 " Meter
Coefficient of Efflux
Pressure Drop - Inches H2O.

8. At each point of the stroke the piston speed can be found from the following table:

Suction Stroke Completed.	Piston Speed Factor.
.0000	0.000
.0796	0.587
.2878	0.954
.5505	1.000
.7878	0.778
.9455	0.413
1.0000	0.000
Exhaust Stroke Completed.	**Piston Speed Factor.**
.0000	0.000
.0543	0.413
.2122	0.778
.4495	1.000
.7122	0.954
.9204	0.587
1.0000	0.000

Actual piston speeds are to be found for any revolutions per minute by multiplying

10. Valve openings are computed in the work for flat seats as the product of the circumference of the inner circle and valve lift, and for conical valves as by the formula:

$$A = \frac{\pi dh}{\sqrt{2}} + \frac{\pi h^2}{2\sqrt{2}} \text{ for small lifts.}$$

11. The first runs were made on the flat seated Daimler valve, with a steady flow of air and the results are given in the curves and tables. In every case the density of the air measured by the meter is reduced to atmosphere and given both ways in the tables. The column called "Theoretical Velocity" is computed on air at atmospheric density by the usual formula of $V\sqrt{2gh}$. The ratio of the actual velocity to the theoretical velocity gives

what is called the "Co-efficient of Efflux," and this appears for atmospheric air as well as for the air at meter density. It will be seen from the tables that the co-efficients computed in this way are nearly alike, and that the error in assuming the air measured by the meter to be not very different from the atmospheric air, is not great and the difference may in general be neglected. In the curves between the pressure drop and co-efficient of efflux it is seen that the co-efficient is greatest for the smallest opening and least for the largest opening. On the assumption of gas density being that of the higher pressure while passing through the valve, it appears from the co-efficient curves that the greater the pressure drop the smaller the co-efficient; on the contrary, when the density is that taken for atmospheric pressure, these co-efficients of efflux seem to be nearly constant for all pressure drops. The exhaust flow, or rather the flow in the opposite direction or flow in the exhaust direction, shows the results that seem to follow similar laws for the inlet, but the velocity and the co-efficients were smaller. The errors involved in the work are not greater than one per cent. for the meter observations, and for valve area computations on the flat valve may be neglected, but may be as much as ten per cent. for valve area computations on the conical valve, in spite of all care.

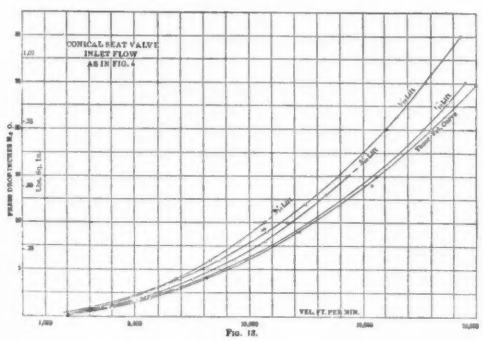


FIG. 12.

CONICAL SEAT VALVES.

(Diameter of opening = 1.5 inches.)

DIRECTION OF FLOW FROM INSIDE TO OUTSIDE OF VALVE AS IN "INLET."

RUN 1 (A).

Valve fixed at 1-20-inch lift. Area of opening = .001351 square feet.

Barometer 30.00 inches Hg. Average temperature of Air = 77 degrees Fahr.

Pressure Drop. (Inches of Water.)	Cubic Feet of Air per Minute.	Velocity. (Ft. per Min.)	Velocity corrected from Curves. (Ft. per Min.)	Theoretical Velocity at 72 deg. Fahr. (Ft. per Min.)	Coefficient of Efflux (Air at Meter Density.)	Coefficient of Efflux. (Air at Atmospheric Density.)
1	4.21	3,160	....	4,020	.786	.788
2	6 30	4,660	4,460	5,685	.820	.824
4	9.41	6,960	....	8,040	.866	.875
6	11.75	8,690	....	9,847	.884	.897
9	14 50	10,720	....	12,060	.890	.910
12	16.80	12,430	....	13,926	.893	.919
15	18.75	13,880	....	15,570	.890	.923
20	21.60	15,990	....	17,978	.889	.935
25	23 95	17,710	....	20,100	.882	.938
30	26.00	19,230	...	22,019	.873	.940
2½" Hg.	27.65	20,250	....	23,420	.864	....
3 " Hg.	30.00	22,200	....	25,370	.875	....
3½" Hg.	31.80	23,530	....	27,720	.849	....
4 " Hg.	33.5	24,800	....	29,630	.836	....
5 " Hg.	36.8	27,210	....	33,130	.823	....
6 " Hg.	38.7	28,620	....	36,302	.789	....

RUN No. 2 (A).

Valve fixed at 1-10-inch lift. Area of opening = .002391 square feet.

Barometer = 29.93 inches Hg. Average temperature of Air = 80 degrees Fahr.

Pressure Drop. (Inches of Water.)	Cubic Feet of Air per Minute.	Velocity. (Ft. per Min.)	Velocity corrected from Curves (Ft. per Min.)	Theoretical Velocity at 72 deg. Fahr. (Ft. per Min.)	Coefficient of Efflux. (Air at Meter Density.)	Coefficient of Efflux. (Air at Atmospheric Density.)
1	9.19	3,841	....	4,020	.925	.927
2	13.20	5,520	....	5,685	.972	.977
3	16.44	6,875	....	6,963	.984	.991
5	21.40	8,950	8,850	8,990	.985	.998
9	29.00	12,120	12,000	12,060	.994	1.013
14	35.68	15,400	14,800	15,042	.984	1.019
20	42.20	17,650	....	17,978	.982	1.033
25	46.50	19,450	....	20,100	.968	1.030
30	50.20	21,000	....	22,019	.954	1.027

RUN No. 3 (A).

Valve fixed at 3-20-inch lift. Area of opening = .00364 square feet.

Barometer = 30.17 inches Hg. Average temperature of Air = 76 degrees Fahr.

Pressure Drop. (Inches of Water.)	Cubic Feet of Air per Minute.	Velocity. (Ft. per Min.)	Velocity corrected from Curves. (Ft. per Min.)	Theoretical Velocity at 72 deg. Fahr. (Ft. per Min.)	Coefficient of Efflux. (Air at Meter Density.)	Coefficient of Efflux. (Air at Atmospheric Density.)
1	13.68	3,755	....	4,020	.935	.931
2	19.45	5,340	....	5,685	.940	.945
3	23.80	6,540	....	6,963	.940	.947
4	27.40	7,525	7,600	8,084	.940	.949
6	33.85	9,300	....	9,847	.945	.959
8	38.85	10,680	....	11,370	.940	.959
10	42.40	11,650	11,850	12,713	.932	.956
13	48.60	13,350	13,400	14,494	.926	.957
15	52.00	14,280	14,300	15,570	.919	.954

RUN No. 4 (A).

Valve fixed at 4-20-inch lift. Area of opening = .00494 square feet.

Barometer = 30.17 inches Hg. Average temperature of Air = 78 degrees Fahr.

Pressure Drop. (Inches of Water.)	Cubic Feet of Air per Minute.	Velocity. (Ft. per Min.)	Velocity corrected from Curves. (Ft. per Min.)	Theoretical Velocity at 72 deg. Fahr. (Ft. per Min.)	Coefficient of Efflux. (Air at Meter Density.)	Coefficient of Efflux. (Air at Atmospheric Density.)
1	17.3	3,500	....	4,020	.870	.872
2	24.25	4,910	....	5,685	.864	.868
3	29.50	5,970	....	6,963	.857	.864
4	33.85	6,850	....	8,040	.853	.861
6	41.50	8,400	....	9,844	.854	.867
8	47.05	9,520	....	11,370	.838	.855
10	52.60	10,650	....	12,713	.838	.859

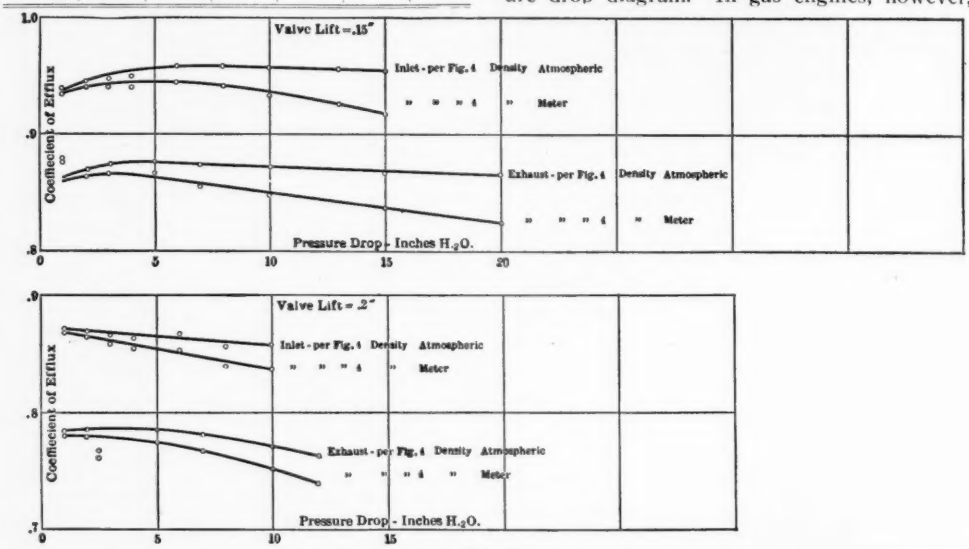


FIG. 17.

13. To most effectively obtain the co-efficient of efflux and their variations with conditions they are plotted in two sets, Fig. 16 for flat valves and Fig. 17 for conical.

INTERMITTENT FLOW.

14. As actually used in the engine the detrimental effect of suction pressure drop is first lost work measured by the mean suction pressure taken by the planimeter from the pressure drop diagram, and second a lost volume or decreased volumetric cylinder efficiency shown by the fraction of stroke at which the compression line crosses atmosphere. The values for these are given in the tables.

Similarly for exhaust or discharge the first effect is one of resistance measured by the mean pressure above atmosphere on the pressure drop diagram. In gas engines, however, the terminal exhaust pressure measures the dilution of fresh charge by hot burnt gases. This is also given from the indicator cards.

CONICAL SEAT VALVE. PART B.
(Valve with housing as in Fig. 3).

DIRECTION OF FLOW FROM OUTSIDE TO INSIDE OF VALVE AS IN "EXHAUST." RUN No. 1 (B).

Valve fixed at 1-20-inch lift. Area of opening = .001351 square feet.

Barometer = 29.69 inches Hg. Average temperature of Air = 77 degrees Fahr.

Pressure Drop. (Inches of Water.)	Cubic Feet of Air per Minute.	Velocity. (Ft. per Min.)	Velocity corrected from Curves. (Ft. per Min.)	Theoretical Velocity at 72 deg. Fahr. (Ft. per Min.)	Coefficient of Efflux. (Air at Meter Density.)	Coefficient of Efflux. (Air at Atmospheric Density.)
1	3.88	2,870	2,900	4,020	.721	.723
2	5.77	4,270	....	5,685	.752	.756
3	7.15	5,280	....	6,963	.758	.764
5	9.40	6,960	....	8,990	.784	.794
7	11.22	8,300	8,200	10,636	.771	.785
10	13.48	9,960	9,880	12,713	.776	.796
12	14.75	10,910	10,800	13,926	.775	.799
15	16.40	12,120	....	15,570	.779	.809
20	18.94	14,100	13,950	17,978	.777	.817
25	20.92	15,470	15,580	20,100	.775	.825
30	22.85	16,910	....	22,019	.767	.827

RUN No. 2 (B).

Valve fixed at 1-10-inch lift. Area of opening = .002391 square feet.

Barometer = 29.81 inches Hg. Average temperature of Air = 77 degrees Fahr.

Pressure Drop. (Inches of Water.)	Cubic Feet of Air per Minute.	Velocity. (Ft. per Min.)	Velocity corrected from Curves. (Ft. per Min.)	Theorecical Velocity at 72 deg. Fahr. (Ft. per Min.)	Coefficient of Efflux. (Air at Meter Density.)	Coefficient of Afflux. (Air at Atmospheric Density.)
1	8.56	3,580	....	4,020	.891	.893
2	12.18	5,080	....	5,685	.894	.898
3	14.92	6,250	....	6,963	.898	.907
5	19.49	8,150	....	8,990	.906	.918
7	22.82	9,560	....	10,636	.899	.915
10	27.21	11,380	....	12,715	.894	.917
15	33.18	13,880	....	15,570	.891	.925
20	37.68	15,780	....	17,978	.878	.923
25	41.30	17,290	17,400	20,100	.865	.920
30	44.30	18,550	18,800	22,019	.855	.922

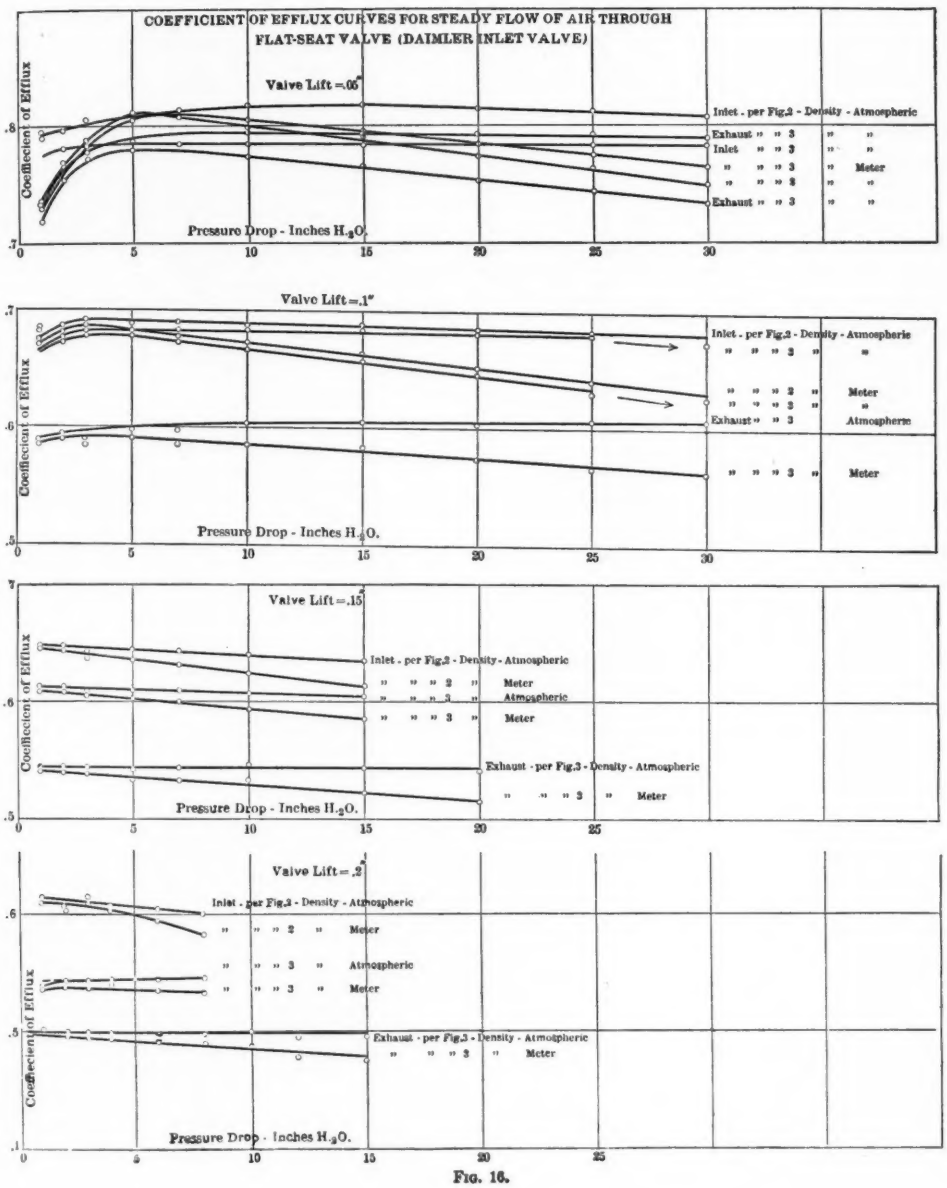

COEFFICIENT OF EFFLUX CURVES FOR STEADY FLOW OF AIR THROUGH FLAT-SEAT VALVE (DAIMLER INLET VALVE)
Valve Lift = .05"
Coefficient of Efflux
Pressure Drop - Inches H2O.
Inlet - per Fig.2 - Density - Atmospheric
Exhaust " " 3 " "
Inlet " " 3 " "
" " " 3 " Meter
" " " 3 " "
Exhaust " " 3 " "
Valve Lift = .1"
Inlet - per Fig.2 - Density - Atmospheric
" " " 3 " "
" " " 2 " Meter
" " " 3 " "
Exhaust " " 3 Atmospheric
" " " 3 " Meter
Valve Lift = .15"
Inlet - per Fig.2 - Density - Atmospheric
" " " 2 " Meter
" " " 3 " Atmospheric
" " " 3 " Meter
Exhaust - per Fig.3 - Density - Atmospheric
" " " 3 " Meter
Valve Lift = .2"
Inlet - per Fig.2 - Density - Atmospheric
" " " 2 " Meter
" " " 3 " Atmospheric
" " " 3 " Meter
Exhaust - per Fig.3 - Density - Atmospheric
" " " 3 " Meter

FIG. 16.

RUN NO. 3 (B).

Valve fixed at 3-20-inch lift. Area of opening = .00364 square feet.

Barometer = 29.84 inches Hg. Average temperature of Air = 80 degrees Fahr.

Pressure Drop. (Inches of Water.)	Cubic Feet of Air per Minute.	Velocity. (Ft. per Min.)	Velocity corrected from Curves. (Ft. per Min.)	Theoretical Velocity at 72 deg. Fahr. (Ft. per Min.)	Coefficient of Efflux. (Air at Meter Density.)	Coefficient of Efflux. (Air at Atmospheric Density.)
1	12.83	3,525	....	4,020	.878	.880
2	17.90	4,920	....	5,685	.866	.870
3	22.00	6,040	....	6,963	.867	.873
5	28 39	7,780	....	8,990	.867	.878
7	33.32	9,120	....	10,636	.857	.872
10	39.38	10,800	...	12,713	849	.871
15	46.70	12,820	13,000	15,570	.835	.867
20	53.85	14,800	....	17,978	.824	.866

RUN NO. 4 (B).

Valve set at 2-10-inch Hg. Area of opening = .00494 square feet.

Barometer = 29.84 inches Hg. Average temperature of Air = 82 degrees Fahr.

Pressure Drop. (Inches of Water.)	Cubic Feet of Air per Minute.	Velocity. (Ft. per Min.)	Velocity corrected from Curves. (Ft. per Min.)	Theoretical Velocity at 72 deg. Fahr. (Ft. per Min.)	Coefficient of Efflux. (Air at Meter Density.)	Coefficient of Efflux. (Air at Atmospheric Density.)
1	15.51	3,140	....	4,020	.780	.782
2	21.9	4,430	....	5,686	.780	.784
3	24 4	4,940	5,300	6,963	.760	.766
5	34.40	6,960	....	8,990	.775	.785
7	40.25	8,150	....	10,636	.766	.780
10	47.25	9,560	....	12,713	.751	.770
12	50 85	10,290	....	13,926	.738	.761

RUN NO. 1 (B). (NASH.)

(2-inch diameter conical seat valve. Intermittent exhaust flow.)

Mean lift of exhaust valve = .535 inch. Average temperature of air = 81 degrees Fahr.

TABLE NO. 1.

Speed R. P. M.	Cubic Feet of Air pumped per Minute.	Mean Resistance to Discharge.	Terminal Discharge Pressure.
80	7.6	...	...
117	10.80	...	...
151	13.80	.2	.8
185	16.50	.25	1.
210	18.25	.3	1.2
253	21.10	.4	2.4
283	23.00	.5	2.6
320	38.20	.6	3.

RUN NO. 2 (A). (NASH.)

(2-inch diameter conical seat valve, intermittant inlet flow, Nash engine.)

Mean lift of inlet valve = .393 inch. Average temperature of air = 80 degrees Fahr.

TABLE NO. 1.

Speed R. P. M.	Cubic Feet of Air pumped per Minute.	Piston Displacement (Cu. Ft. per Minute.)	Per Cent. lost volume	Mean Resistance to Suction.
102	9.46	9.79	5.32	...
138	12.53	13 23	5.29	...
176	16.21	16.90	4.08	.17
208	18.94	19.99	5.26	.25
247	22.10	23.72	6 84	.57
296	26.02	28.42	8.44	.71

INTERMITTENT FLOW. CONICAL SEAT EXHAUST VALVE. (DAIMLER ENGINE.)

RUN NO. 1 (B).

(1.25-inch conical seat valve. Intermittent exhaust flow.)

Mean lift exhaust valve = .333 inch. Average temperature of air = 85 degrees Fahr.

Max. lift inlet valve = .10 inch.

TABLE NO. 1.

Speed R. P. M.	Cubic Feet of Air pumped per Minute.	Mean Resistance of Discharge.	Terminal Discharge Pressure.
150	2.83	...	...
200	3.69	...	...
250	4.63	...	about .1
300	5.56	.1	.20
350	6.54	.1	.2
400	7.56	.15	.3
450	8.50	.15	3
500	9.39	.15	.3
570	10.41	.25	.5

INTERMITTENT FLOW. CONICAL SEAT VALVE. (NASH ENGINE).

RUN NO. 1 (A).

(1.5-inch conical seat valve, cam opened, intermittent inlet flow.)

Mean lift of exhaust valve = 226 inch. Average temperature of air = 80 degrees Fahr.

Max. lift inlet valve = .10 inch.

TABLE NO. 1.

Speed R. P. M. (Average during run.)	Cubic Feet of Air pumped per Minute.	Piston Displacement. (Cu. Ft. per Minute.)	Per Cent. lost volume.	Mean Resistance to Suction.
63	4.66	5.09	3.30	.36
96	8.73	9 22	5.32	.53
116	10.25	11.13	7.79	.64
140	12.23	13.43	9 00	.73
161	14.19	15.45	8.15	1.07
185	15.75	17.75	11.28	1.29
205	17.10	19.70	13 21	1.35
225	18.35	21.60	15.05	1.64
237	19.10	22.75	16.05	1.68
250	19.60	24.00	18.34	2.07
2»8	21.20	27.65	23.30	2.30
316	22.65	30.32	25.30	2.65

FLOW OF AIR THROUGH CIRCULAR ORIFICES UNDER LOW HEADS

The following is an abstract from a long experimental investigation reported by Mr. R. J. Durley (Montreal, P. Q.) in a paper read before the American Society of Mechanical Engineers, entitled "On the Measurement of Air Flowing Into the Atmosphere through Circular Orifices in Thin Plates and Under Small Differences of Pressure." The work covered heads of 1-in. to 5 ins. water, and orifices up to 4 ins. diameter. The following formula was adopted to express the results:

Discharge in pounds per second,

$$= 0.6299 \ C \ d^2 \ \sqrt{\frac{i}{T}},$$

where C is an experimental coefficient;

d = diameter of orifice in inches;

i = pressure difference in inches of water;

T = absolute temperature of the air, Fahr.

The following values were found for the coefficient C:

COEFFICIENTS OF DISCHARGE FOR VARIOUS HEADS AND DIAMETERS OF ORIFICE.

Diameter of Orifice Ins.	1-in. Head.	-in. Head.	3-in Head.	4-in. Head.	5-in. Head.
5.16	0.603	0.606	0.610	0.613	0.616
½	0.602	0.605	0.608	0.610	0.613
1	0.601	0.603	0.605	0.606	0.607
1½	0.601	0.601	0.602	0.603	0.603
2	0.600	0.600	0.600	0.600	0.600
2½	0.599	0.599	0.599	0.598	0.598
3	0.599	0.598	0.597	0.596	0.596
3½	0.599	0.597	0.596	0.595	0.594
4	0.598	0.597	0.595	0.594	0.593
4½	0.598	0.596	0.594	0.593	0.592

(Barometer at 30 ins.)

The general conclusions are thus stated:

(1) The coefficient for small orifices increases as the head increases, but at a lesser rate the larger the orifices, till for the 2-in. orifice it is almost constant. For orifices larger than 2 ins. it decreases as the head increases, and at a greater rate the larger the orifice.

(2) The coefficient decreases as the diameter of the orifices increases and at a greater rate the higher the head.

(3) The coefficient does not change appreciably with temperature (between 40° and 100° F.).

(4) The coefficient (at heads under 6 ins.) is not appreciably affected by the size of the box if the ratio of the areas of the box and orifice is at least 20:1.

The orifices used were bored (straight) in iron plates No. 15 B. & S., or 0.057-in. thick. The experiments were made at McGill University, Montreal, by Messrs. F. E. Sterns and G. M. Smith.

A COMPRESSED AIR FIRE ENGINE

A most interesting application of Compressed Air has just been made by the city of Norwich, Connecticut. The city has a central compressed air power plant in which the air is compressed by hydraulic machinery and distributed throughout the city in mains laid beneath the streets. Fire Chief Stanton states that as this air is distributed throughout the principal business streets, he has decided to have connections made with all the hydrants in the business district; it will then be possible to connect the fire engines directly to the source of compressed air supply and operate them in that way.

Air is supplied under 90 pounds pressure and it has been demonstrated that such a pressure for compressed air will do the same work as 110 pounds of steam, owing to the fact that the air pressure is always steady and does not run down under any conditions.

The city has just purchased a new American La France fire engine, known as the Metropolitan style, and this engine has been equipped with an extra throttle and air hose connection, to reach from the curb to the engine, about ten feet long. It will then be possible to connect with the compressed air supply at the same time that the water connection is made, and the engine can be started up without delay.

The idea of operating the fire engines of Norwich by compressed air originated with Howard L. Stanton, Chief of the Fire Department. He states that in case they have any trouble with freezing at the exhaust, a small fire will be started in the boiler; thus far, however, the engines have not been given a sufficient test under the new conditions to determine how practicable this system is.

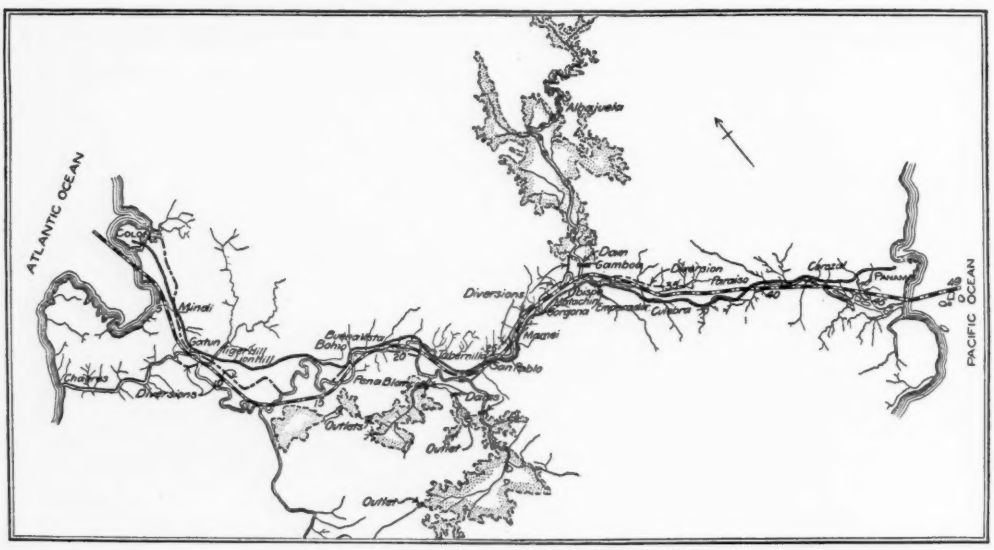
UNIVERSITY OF ILLINOIS

A liquid air plant has been set up by the Department of Physics. The liquefier is a Hampson apparatus, imported from London. It receives air compressed to 2,500 to 3,000 pounds. The compressor belongs to the Department of Mechanical Engineering, and is a four-cycle machine, made by the Norwalk Iron Works. The capacity of the liquefying plant is about one liter per hour, to produce which about 10 H.P. is required. It is said that only two or three other American universities own liquid air plants.

THE REPORT OF THE CONSULTING ENGINEERS FOR THE PANAMA CANAL*

The most important document in the engineering history of the Panama Canal to date is probably the report of the Board of Consulting Engineers, consisting of Maj.-Gen. George W. Davis, chairman; Mr. Alfred Noble, chief engineer of the East River Division of the Pennsylvania, New York & Long Island R. R.; Mr. William Barclay Parsons, until recently chief engineer of the New York Rapid Transit Railroad Commission; Prof. William H. Burr, of Columbia University, consulting engineer of the Board of Water Supply of New York City; Brig.-Gen. Henry L. Abbot; Mr. Frederic P. Stearns, chief engineer of the Metropolitan Water and Sewerage Board; Mr. Joseph Ripley, general superintendent of St. Mary's Falls Canal; Mr. Isham Randolph, chief engineer of the Sanitary District of Chicago; Mr. William H. Hunter, chief engineer of the Manchester Ship Canal, nominated by the British government; Mr. Eugen Tincauzer, nominated by the German government; Mr. Adolph Guérard, nominated by the French government; Mr. E. Quellennec, consulting engineer of the Suez Canal Co.; Mr. J. W. Welcker, nominated by the Netherlands government. Capt. John C. Oakes, Corps of Engineers, General Staff, U. S. A., was appointed secretary of the Board by the President. The first meeting of the Board was on September 1, 1905, and its report is dated January 10, 1906.

By order of the President there were submitted to the Board for its consideration "the various plans proposed to and by the Isthmian Canal Commission." These included a plan prepared by the old commission on isthmian routes, one prepared by the Technical Committee of the New Panama Canal Commission, three projects prepared by Mr. Lindon W. Bates, the more important results of recent surveys, a paper prepared by Mr. B. Bunau-



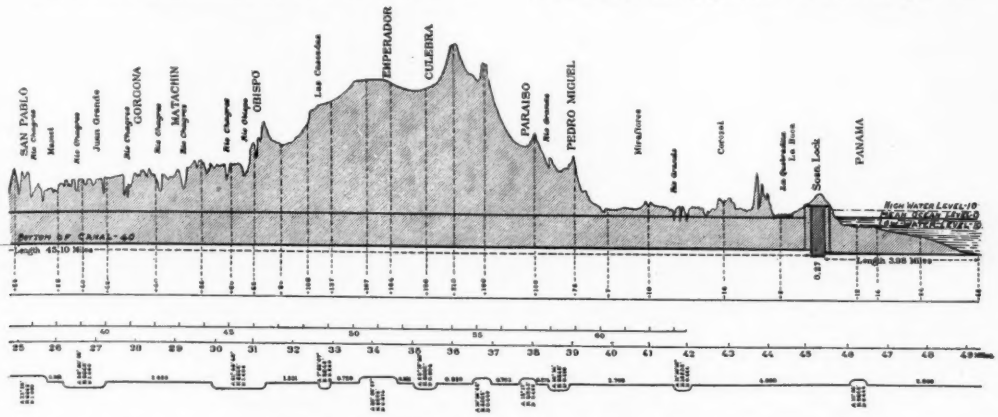
Varilla on his proposed method of constructing the canal, a project by Major Cassius E. Gillette, Corps of Engineers, U. S. A., and a paper on the Gatun dam by Mr. C. D. Ward.

As a basis for all plans, the Board resolved by a vote of 11 to 2 that locks should be at least 1,000 feet long, 100 feet wide and 40 feet deep. It decided unanimously that in order to make its estimates comparable with those of previous commissions, there should be added to the estimated cost of construction an allowance of 20 per cent. for administration, engineering and contingencies, but exclusive of interest during construction, sanitation, the expense of Zone government and collateral costs. The Board also decided not to attempt to make any estimate of cost of the lands to

*Taken from full report as published in Engineering Record.

be flooded by the canal or lakes connected with it, on account of the impossibility of procuring reliable information on which to base such estimates. The Board points out, however, that such costs may assume large proportions, especially if lands near cities and villages should be required.

The Board determined by a vote of eight to

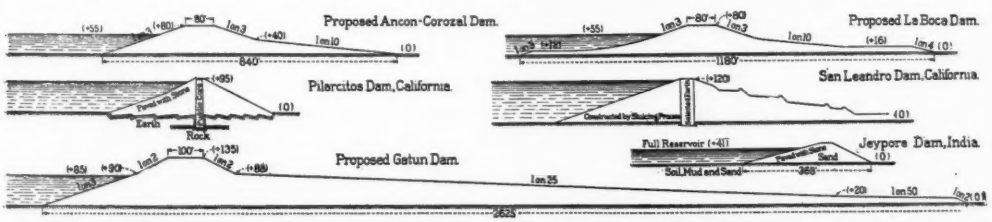


five to adopt, for comparison with a sea-level canal, one with its summit level at El. 60 feet. It decided that there should be duplicate locks at Sosa, Pedro Miguel, Gatun and Bohio, and a dam at Gamboa for the regulation of the Chagres. This plan is not the most feasible for subsequent conversion to a sea-level canal, for the Board agreed as to the impracticability of converting a lock canal to one at sea level, in the immediate future, on account of the difficulty and danger of the operation and its excessive cost.

In regard to the time required to construct the two canals, the Board resolved, by a 7 to 6 vote: "That the Board declare in its report that the time of finishing the sea-level canal depends on many contingencies that cannot be definitely estimated in time; that under efficient management and not seriously affected by extraordinary and unforeseen difficulties, political obstructions or bad sanitation it may be regarded as feasible to complete the work in about twelve or thirteen years; that adverse conditions may lengthen that period, while favorable circumstances and conditions first-class direction may make it possible to shorten that period by one or two years." It was unanimously resolved in similar language that the canal with locks on the plans prepared by the Board may be constructed in ten to eleven years.

The Board finally passed the following resolution, Messrs. Davis, Parsons, Burr, Hunter, Guérard, Quellennec, Tincauzer and Welcker voting for it, and Messrs, Abbot, Noble, Stearns, Randolph and Ripley against it:

"Whereas, in the judgment of this Board, a sea-level canal is feasible, following a line with dimensions and such arrangements that the transit between the two oceans shall be secured in a permanent manner for all time under the best conditions for navigation and safety, for vessels of the largest tonnage and greatest draft now in use, or such as may be reasonably anticipated: Therefore,



"Resolved, That the Board adopt and recommend to the President of the United States, the plan of a sea-level canal with a depth of 40 feet, a width in rock of 200 feet, a minimum bottom width in earth of 150 feet, with a double tidal lock at Ancon, whose usable dimensions shall be 1,000 feet in length and 100 feet in width, and with a dam at Gamboa for the control of Chagres River."

In accordance with this decision, the Board submitted a general plan for a sea-level canal.

THE PROPOSED TUNNEL UNDER THE DETROIT RIVER FOR THE MICHIGAN CENTRAL R. R.*

Construction work will soon be in progress on a second railway tunnel crossing the Detroit River. In 1890 the Canadian and American lines of the Grand Trunk Railway were physically connected across this important waterway by a tunnel at Sarnia. Previously a car ferry had been necessary to transfer trains from one shore to the other. Such a ferry still continued in use for the other great international line, the Michigan Central R. R. The thought was always in mind, however, that ultimately the physical connection of the lines should be made perfect by bridge or tunnel. At first, attention was directed chiefly toward a bridge crossing, but lately the company's engineers gave most of their study to a possible tunnel crossing, and this is the type of crossing that has been finally decided upon and that is soon to be put under construction, unless all present plans go seriously awry.

As soon as a tunnel crossing had been decided upon a special organization, known as the Detroit River Tunnel Co., was brought into being to carry out the work. This company immediately began with a large force of engineers to prepare plans, and such progress was made that designs and specifications were virtually completed late in 1905, and on February 1, of the present year, they were in final shape for asking bids for construction. It may be noted that all this work and that all the remaining work of design and construction comes under the direction of an Advisory Board of Engineers, composed of Mr. W. J. Wilgus, M. Am. Soc. C. E., Chief Engineer New York Central & Hudson River R. R.; Mr. Howard A. Carson, M. Am. Soc. C. E., Chief Engineer Boston Transit Commission, and Mr. W. S. Kinnear, formerly Chief Engineer and now Assistant General Manager Michigan Central R. R. Mr. Kinnear will have charge of the tunnel work as Chief Engineer after contracts are let.

In order to widen the field of bidders and enable such a free presentation of ideas as would lead to the utmost reduction of hazard and increase in speed and economy of work, a scheme somewhat unusual in preparing contract drawings for tunnel work was adopted. Alternative designs were worked out, any one of which the bidder is free to choose, and, in addition, he is invited to present plans of his own, should he wish to do so. With these preliminary explanations, the description of the plans may be taken up.

GENERAL DESCRIPTION.

The longitudinal profile of the tunnel is slightly different for each tube, and also differs somewhat for different designs. The drawing, Fig. 1, shows the profile along the center of the west-bound track tube, which, being the outside tube on the curve, is 5.46 ft. longer between portals than is the inside tube,

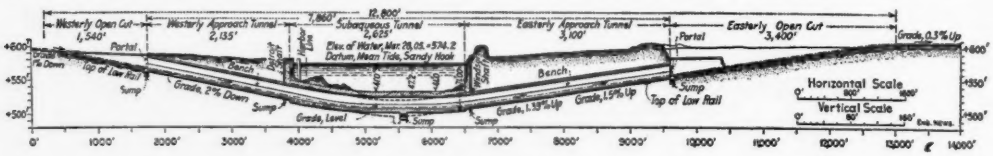


Fig 1.

or the tube for the east-bound track. The profile shown by Fig. 1 is that for design A; the profiles for designs B and C are almost identical with that for design A, but the profile for design D is slightly different, the tubes being deeper under the river bed and the relative lengths of approach tunnels and subaqueous tunnel being changed. For comparison, design D profile has been drawn in dotted outline on Fig. 1, which thus indicates all the essential details in longitudinal profile of all four designs.

The tunnel will penetrate a mixture of blue clay and sand for its entire length. This material was determined by churn drill borings made one on each side of the line every 100 feet of its length between the ends of the approach retaining walls and by four test pits, one close to the water's edge on each side of the river and one further inside on each side. The borings were made with a churn drill working inside a 2½-in. diameter casing while water was being forced through the 1 15-16-in. diameter hollow drill bar. In addition to ob-

*From Engineering News.

serving and recording the wash samples, the resistance to penetration of the drill was observed and core samples were taken in many of the holes at points contiguous to the tunnel bore. According to the resistance to penetration records, the clay at the depth of the tunnel bore is classified as soft. Judging from the test pit records, however, it appears to be a medium to stiff blue clay, with a varying and at no time large content of sand and gravel. According to the test pit observations also, this clay gave very little water; a considerable flow came from the sand and gravel

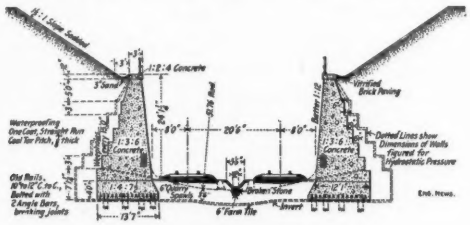

Vitrified Brick Paving
Waterproofing One Coat, Straight Run Coal Tar Pitch, ¼ Thick
Concrete
Dotted Lines show Dimensions of Walls figured for Hydrostatic Pressure
Old Rails, Weight 72 C. to C., Bolted with 2 Angle Bars, breaking joints
Broken Stone
6" Farm Tile
Sewer
20'6"
80'
137'
Eng. News.

Fig. 2.

strata above the clay bed and from the sand stratum at the bottom of the river.

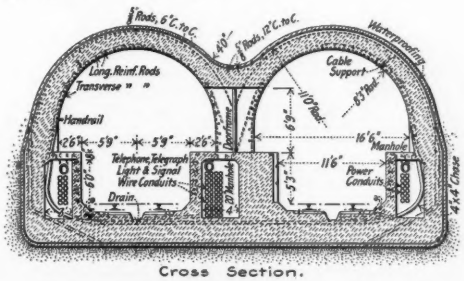
As certain of the proposed designs call for stagings in the river, the sinking of sections of steel or timber forms, and the depositing of concrete through the water, careful observations were made of the current velocities. Considerable irregularity is shown by the meter readings, which were taken at four or five depths about every 200 feet across the river; but, generally speaking, the surface velocities were slightly above or below 3 feet per second, and the bottom velocities were from 1.17 feet to 2.29 feet per second.

Returning to the profile, Fig. 1, it is to be noted that the open cut approaches and the approach tunnels are the same in construction for all four designs, except that in design D they are of somewhat less length than in the other designs. The subaqueous tunnel construction is, however, different in each design.

LAND TUNNELS AND APPROACHES.

Designs A, B and C all call for a 1,540-ft. open cut and a 2,135-ft. approach tunnel on the west shore and a 3,400-ft. open cut and a 3,100-ft. approach tunnel on the east shore. In design D the open cuts are of the same length as in the other designs illustrated by Fig. 2, but the west approach tunnel is only 2,069 feet long and the east approach tunnel only 3,007.34 feet long. Except for this difference, the open cut and the approach tunnel construction is the same for all designs.

OPEN CUT CONSTRUCTION.—The open cuts flanking the tunnel proper at each end call for brief description only. They are simply earth cuts, with 1 on 1½ slopes in the shallower portions and retained banks in the deeper portions. The cross-section, Fig. 2, taken near the portal on the east shore, indicates clearly the retaining wall construction. This drawing shows a concrete invert between walls and bracing them apart; this invert extends 306 feet from the east tunnel portal and 745 feet from the west tunnel portal. Beyond the ends of inverts the walls are braced apart ("where directed by the engineer") by struts consisting of steel rails embedded in concrete, spaced 15 feet apart. Practically the only other general detail not shown by the drawing is the cutting of the walls vertically by transverse tar-paper joints every 50 feet to provide for expansion.



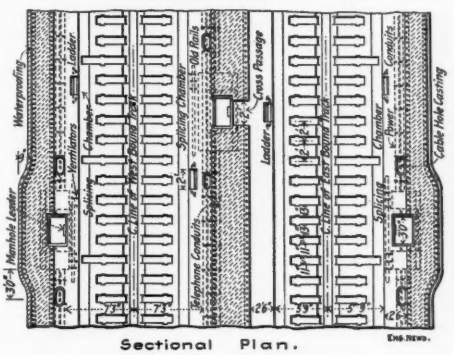
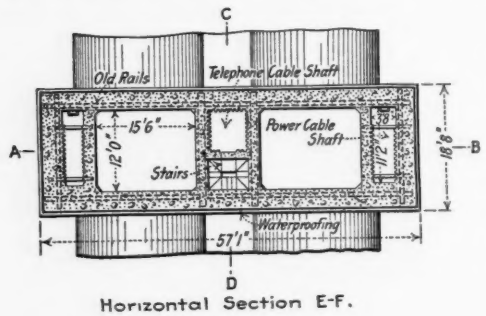


Fig. 3.

APPROACH TUNNELS.—The two approach tunnels are substantially identical in construction. Each consists of two single track tubes separated by a concrete center wall and lined with concrete, which shall or shall not be reinforced, as the engineers direct. The

drawing, Fig. 3, shows a normal section. This section happens to be at a point where a cross passage and the conduit splicing chambers are cut. The cross-passages occur every 200 feet, and the splicing chambers every 400 feet; between these openings the center wall and benches are solid concrete embedding the ducts. Referring to the drawing, Fig. 3, attention may be called to the cable holes connecting with the splicing chambers and to the slots for cross-ties in the concrete floors. The other details are sufficiently clear from the drawings.

The method of constructing the approach tunnels will be determined by the contractor, subject to the approval of the engineer.



Horizontal Section E-F.

Fig. 4.

SHAFT CONSTRUCTION.

To facilitate construction, the contract plans provide for a shaft on each side of the river; the locations of these shafts are shown in Figs 1 and 2. The design is practically the same for both shafts, and is indicated clearly for the west shore shaft by Fig. 4. As will be seen, a very substantial structure of concrete is planned, since it is to serve as a permanent shaft after construction is finished.

RIVER TUNNEL PLANS.

The contract plans offer four designs of tunnel for the portion of the work coming under the river. These are designated as trench methods A, B and C, and shield method D. In addition, the bidders are permitted to present plans of their own, should they choose to do so. Each design is described separately in the following sections from information given in the specifications:

DESIGN A, TRENCH METHOD.—The design shown in the profile, Fig. 1, is one suggested by Mr. W. J. Wilgus, of the Advisory Board of Engineers, who states its advantages to be "reduction in lift of traffic, saving in time of construction, minimizing of risks and large saving in first cost." It may be briefly described as a method by which the pervious material underlying the river is replaced by an impervious concrete placed under water, through which, without the use of shields, the inner tubes or tunnel proper may be constructed so as to secure water tightness, continuity of strength and good workmanship, with an absence of high air pressures. It will also be noted that this method dispenses with the use of cofferdams. The progressive stages for this design are:

(1) Dredging a trench for the approximate dimensions. While certain slopes are assumed as proper for the purpose, the contractor is expected to inform himself on this point and make proper allowance in his bid for contingencies that may require flatter slopes, and therefore more excavation than is indicated upon the plan. The contractor will be given latitude as to the method he prefers to adopt in the use of flatter slopes than shown on the plan or of temporary sheet piling for the retention of slopes within the opproximate cross-section of the plan.

(2) Depositing of "two-men" stone for a depth of 18 inches on the bottom of the trench, so as to form a blanket or barrier between the underlying clay and sand and the superimposed concrete.

(3) The construction of temporary platforms in accordance with the permits of the United States and Canadian governments, upon which the contractor's machinery, including mixers, etc., may be placed for the operations herein described; said platforms to move progressively across the river as the dredging and other work permit.

(4) Depositing of concrete by the tremie, bucket or other process approved by the engineer for a depth of approximately 2 feet.

(5) The placing of saddles with the aid of blocking and wedges upon said bed of concrete, upon which the forms are to be placed as herein described. As an alternative method, piling may be driven after the trench is excavated and cut off at a proper height to receive the saddles, so as to dispense with the use of blocking and wedges.

(6) The construction on shore and floating into position of forms coupled together in pairs or otherwise, consisting of timber or

steel, as preferred by the contractor, in convenient lengths of 50 to 500 feet, and gradually sunk into correct position on the saddles above described.

(7) Placing under, around, between and on top of the forms concrete by the bag, tremie or bucket process, as may be determined by the engineer during the progress of the work as best qualified to insure good workmanship, so as entirely to encase the forms with concrete in the manner shown. The option is left to the contractor of either joining adjacent forms under water in such a manner as to secure watertight connections or of leaving an open space between them to be filled with concrete as above described, so as to act as a bulkhead separating the adjacent forms, to be cut out after the water has been expelled as hereinafter described.

(8) After the concrete placed under water has had an opportunity to set thoroughly, the water may be pumped out of the first section, and if the leakage is found to be excessive, air may be used of a sufficient pressure to enable the waterproofing to be perfected and the inner tube or tunnel to be properly constructed.

(9) Should the contractor elect to adopt rolled steel for the forms, they shall be constructed with watertight joints in such a manner that, left in the work, they will act as waterproofing to prevent the percolation of water against the exterior of the inner tubes of the tunnel proper. Should the contractor elect to use wooden forms, waterproofing may be placed on the exterior of the forms before they are sunk into position, so that when the forms are removed the waterproofing will remain in place. This method will require the use of air pressure to prevent hydrostatic pressure from distorting the waterproofing.

(10) After proper measures have been taken to make each section thoroughly watertight, the inner tubes of the tunnel proper shall be constructed with metal reinforcing in the manner and of the classification of concrete shown on the plans.

DESIGNS B and C, TRENCH METHOD —Design B may be briefly described as a method by which the inner tubes of the tunnel proper are first built in floats or on dry land, floated and sunken into position on a proper foundation and joined together by a suitable method, so as to secure continuity of construction and watertightness. This design was suggested by Mr. H. A. Carson, of the Advisory Board of Engineers, and is shown by Fig. 5. The progressive stages for this design are:

(1) The dredging of a trench, the depositing of "two-men" stone, the construction of a temporary platform, 2-ft. bed of concrete and the placing of saddles in the same manner as described for Design A.

(2) The tubes, after being floated into position, are to be gradually sunk to a proper bearing on the saddles and a proper joint made at the connection of the tubes, so as to insure watertightness and an equality of strength with the remaining portions of the tube, so that the joint will not be an element of weakness in the structure and will be fully as strong as any portion thereof.

(3) Around, between and under the lower portion of the tubes is to be placed the concrete as shown by Fig. 6.

(4) Above the concrete and around and on top of the tubes is to be placed a black filling of suitable material approved by the engineer.

(5) On the top of the back filling is to be placed riprap as shown on the plan.

Design C is practically the same as Design A, with the exception of the details which prescribe a certain style of steel form and arrangement of Design A.

DESIGN D, SHIELD METHOD.—The option is given to bidders of selecting the well-known shield method of construction, Design D, if they do not feel warranted in bidding on other methods. The necessity, however, of retaining the summits of the tunnel gradients at the point shown on the plan causes a location of the top of the tunnel for the subaqueous section so close to the river bed as to require artificial filling in order to hold air by the shield method. Therefore, the contractor bidding upon this method must bear in mind the necessity of placing temporary blankets or masses of clay on top of the location of the tunnel, so as to give the necessary thickness between the top of the shield and the water, to prevent or reduce the escape of compressed air. Fig. 6 is a cross-section of the shield-driven tunnel, and its profile is shown by dotted lines on Fig. 1.

METHODS OF CONSTRUCTION.

The contract plans specify materials and

general methods of construction, and some of the clauses relating to methods of construction, and particularly to the manner of conducting work by the trench method, are of importance and novelty enough to abstract briefly.

DEPOSITING CONCRETE.—The large amount of concrete to be deposited under water is a distinctive feature of all the designs by the trench method. The method for depositing this concrete may consist of a selection of the tremie properly designed to fit local conditions, drop-bottom buckets or bags. If tremies are used, they shall be constructed of steel, handled by power, so as to be easily adjusted in moving from place to place, and designed so as to give a slow, uniform movement of the mass in passing from the mixing platform to the point of deposit. As a rule, the tremie shall first be filled with concrete, which shall be allowed to escape slowly at the bottom, with the aid of a diver, concrete being placed in at the top as fast as it passes out at the bottom. In this manner the only point where there is danger of washing away of the cement from the aggregate is in the adjusting of the concrete from the bottom of the tremie to its final position. Care should be taken by the diver that the concrete has no fall through the water, but oozes out so as to cause a minimum disturbance of the material. In passing under and around the tubes it may prove necessary to have curved adjustable lengths provided at the bottom of the tremie for depositing the concrete in places that would be inaccessible for straight tubes.

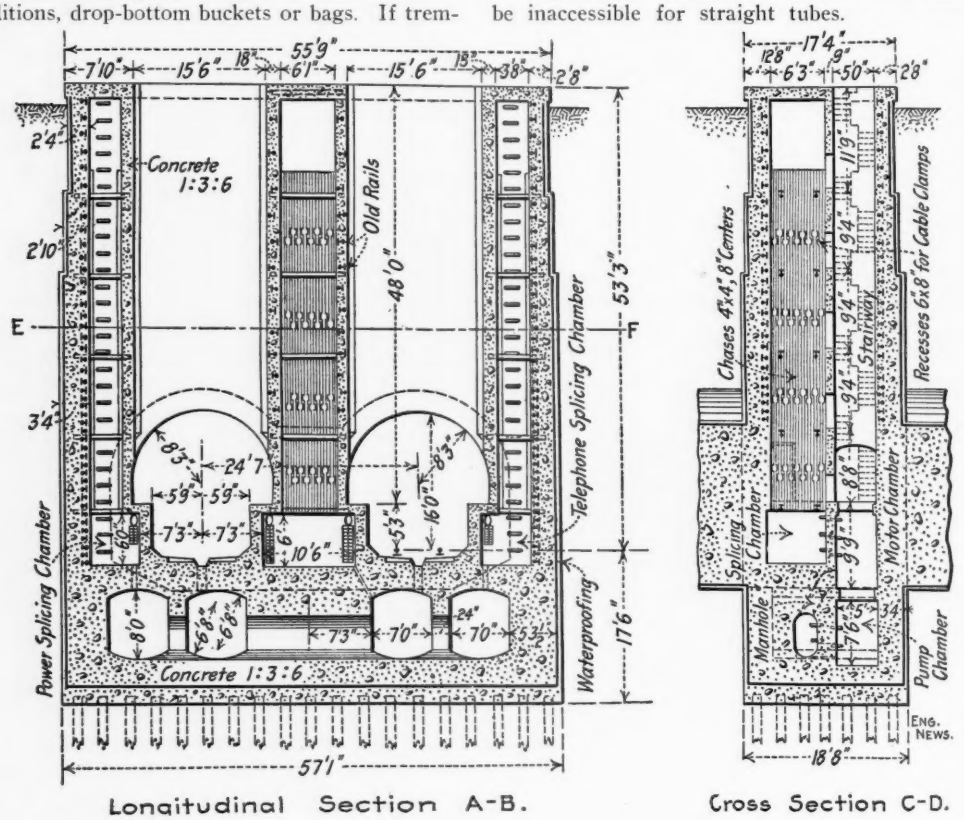


Fig. 5.

Where drop-bottom buckets are used, they shall be filled on the mixing platforms and the tops closed, so as to prevent the washing away of the cement in passing through the water. They shall not be dumped until the bucket is close to the point of deposit, so that the concrete will not fall through the water.

Where bags are used, the concrete shall be placed therein on the mixing platforms and lowered to the diver, who shall pack them closely into position, so that the cement ooz-

ing through the mesh of the bags will bind the entire mass together.

The proper one of the three above methods shall be adopted, with the approval of the engineer, to best fit conditions as they arise. For instance, in order to prevent an uplifting effect on the tubes and to guarantee a continuous and thorough support for the underside of the tubes, the engineer may require the use of bags instead of the tremie or bucket method for that portion of the work. Where cavities exist beneath the lower semi-circumference of the forms, the holes that have been provided in the forms shall be opened and grout shall be forced into the surrounding materials by means of a suitable machine, which will mix the grout continuously and permit the application of a pressure of 60 pounds per square inch in excess of the water pressure. Sufficient grout shall be used to fill all voids that can be detected from the interior of the forms.

STEEL FORMS FOR DESIGN A.—If steel forms are selected by the contractor, they shall be suitably internally braced, so as to prevent distortion in the process of floating into position and sinking on the saddles and to prevent injury during the placing of the exterior concrete and after the water has been exhausted from the interior thereof. The contractor has the option of using several different methods of preventing the distortion of these forms, by various types of interior bracing or by means of vertical pipes projecting far enough above the level of the river surface to cause a hydrostatic pressure on the forms that will prevent distortion; or, in lieu thereof, the use of pumps to cause the same effect. It is expected that with suitable methods of bracing and the hydrostatic method above suggested it will be possible to make these forms in length as great as 500 to 600 feet, although convenience in the process of sinking may cause the contractor to prefer shorter lengths.

All joints in the tubes shall be thoroughly ship-caulked, so that when pumped out the forms will be watertight under maximum hydrostatic pressure. It is expected that the forms will be deposited in exact position, so that the thickness of the interior tubes or tunnel proper, as shown on the plans, may be obtained, but provision has been made for a maximum variation of 3 inches. Therefore, special precautions will be required to prevent distortion or improper placing of the forms.

Should the contractor elect to join abutting forms under water, so as to secure watertight joints, temporary steel bulkheads should be provided, so that in case of accident the completed portion of the tunnel will not be affected. If, however, the contractor elects not to join abutting forms under water, sufficient separation shall be allowed to secure a bulkhead of concrete placed under water in conjunction with the placing of the remainder of the exterior concrete, which may be cut away as the work advances. After this bulkhead has been removed steel sleeves of the same thickness and design as the forms shall be inserted, lapping a suitable distance into each of the abutting forms, with the joints thoroughly caulked to the satisfaction of the engineer, so as to form a continuous watertight structure. Suitable frequent holes shall be provided, closed with screw plugs, through which grout shall be forced when required by the engineer, to fill cavities that may remain between the outside of the lower semi-circumference of the forms and the exterior concrete.

WOODEN FORMS FOR DESIGN A.—If wooden forms are selected by the contractor, the designs therefor, including the saddles, shall first be submitted to the engineer for his approval. The contractor may have a selection of two methods of placing the waterproofing in connection with these forms, either by placing the same in connection with waterproofing on the exterior of the forms before they are launched and floated into position and filling cavities with grout as described for steel forms, or waterproofing may be placed on the face of the exterior concrete after the wooden forms have been removed and cavities filled with concrete to present a smooth surface on the intrados. In either case the engineer will require that the waterproofing shall be first class in every respect and continuously watertight before the placing of the interior tube or tunnel proper is permitted. With the use of wooden forms, it is expected that compressed air of moderate pressure will be required to repel leakage, so as to permit the placing of the waterproofing and the holding of the same in position pending the construction of the interior tubes.

STEEL FORMS FOR DESIGN C.—The forms for Design C are shown in detail upon the plan, and are to be connected under water

in such a way as to make watertight joints. A number of alternative plans have suggested themselves to the tunnel company, but it has been deemed best to leave this detail to the contractor, selecting this method upon which to make his bid. A description and plan of the contractor's method of performing this detail should accompany his bid.

DESIGNS A AND C.—The inner tubes or tunnel proper for Designs A and C will consist of concrete of the classifications and dimensions shown on the plan, including splicing chambers, cross-passages, bench walls, track construction, single-way ducts, handrails, gaspipe conduits for electric lighting, steel reinforcement and all other work incidental thereto. This work will be performed in the dry in sections, after the forms have been placed and made thoroughly watertight to the satisfaction of the engineer. It is expected that the lining will be laid continuous-

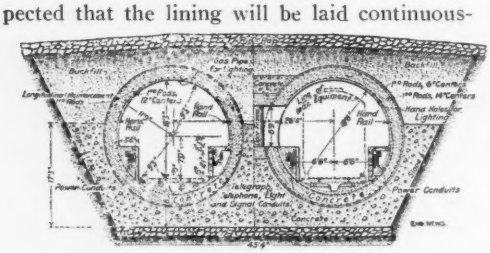


Fig. 6.

ly, so that with the aid of the metal reinforcement the inner tubes will be homogeneous and of uniform strength from end to end.

DESIGN B.—For Design B the tubes will be constructed in floats or on shore, in suitable lengths, of the classifications of concrete shown on the plan, with metal reinforcement and temporary bulkheads. The tubes are to be tested by exhausting the air therefrom, or by any other approved method to make reasonably sure that they are watertight. The tubes will then be floated into position and gradually sunk until they reach a bearing upon the saddles that have been previously placed. Each tube as it reaches a bearing will be brought into as close contact as possible with the one that has been previously placed; the joint shall be made entirely waterproof, and the tubes connected in a manner that will give as great a degree of strength at the joint as in the body of the tube. In other words, the joint shall not be an element of weakness in the finished tubes, either as regards watertightness, durability or strength.

SHIELD METHOD.—The number of shields employed shall be large enough to permit work on at least two faces at once. The shields are to be erected in shield chambers, which shall be an enlargement of the irregular section of the tunnel adjacent to the shafts sufficient to permit the contractor to properly erect the shields. The bulkheads or stopwalls closing the spaces between the enlarged sections and the ordinary tunnel sections shall be formed either with special castings or with concrete, as the engineer may require. Before starting the shield forward after its erection, a standard cast-iron lining shall be built up temporarily within the enlarged section and within the tail of the shield to perfect shape, alinement and grade to start the permanent lining from and to form a thrust bearing for the shield. After moving the shield out of the enlarged section, all of the cast-iron lining thus temporarily placed shall be removed and the section filled in to normal cross-section, as shown on the plan.

The air shall be delivered into each heading through two supply pipes of such capacity that the velocity of air through them in regular working shall not exceed 40 feet per second. These pipes shall be tapped with regulating valves in each intermediate air chamber in tunnels, and sufficient air admitted to ventilate it and to maintain the pressure required. If required by the engineer, air shall be delivered at the shield in each section or compartment thereof where men are employed, and withdrawn therefrom in special exhaust pipes, with suitable regulating valves.

A foul air vent pipe, 8 inches in diameter, shall be carried back from the shield through each lock bulkhead to the ordinary atmosphere to ventilate the heading, and shall be provided with a 10-in. pressure regulating valve near the shield to maintain the pressure required; the valve shall be so placed as not to be readily tampered with.

Effective means shall be used to secure proper ventilation. The amount of carbonic acid at any working face in any chamber must never exceed one part in one thousand parts of air, and compressors must be run so as to maintain at all times a change of air through the pressure regulating valves. Suitable devices shall be used to deaden the noise of air introduced and exhausted as much as practi-

cable. When blasting is resorted to special means must be provided for the rapid removal of the fumes produced.

Bulkheads shall be built in each tunnel at intervals not exceeding 1,000 feet, and there shall at no time be an interval of more than 1,000 feet between a shield and the bulkhead nearest to it. They shall be of concrete or of brick set in Portland cement mortar. Each bulkhead shall be provided with two air locks near the bottom at least 6 feet in diameter and 20 feet long for the passage of men and materials, one near the roof as an emergency lock for the passage of men only and a pipe lock 12 inches in diameter and 31 feet long with a gate valve at each end for passing pipes and rails. The emergency lock shall be of ample dimensions to contain the entire force employed at any time at the heading. Stairways and galleries extending the full length of the forward air chamber shall always be maintained to give convenient access thereto and for the purposes of setting out lines and inspection. All parts of bulkheads and air locks must be of sufficient strength to sustain a pressure of 45 pounds per square inch.

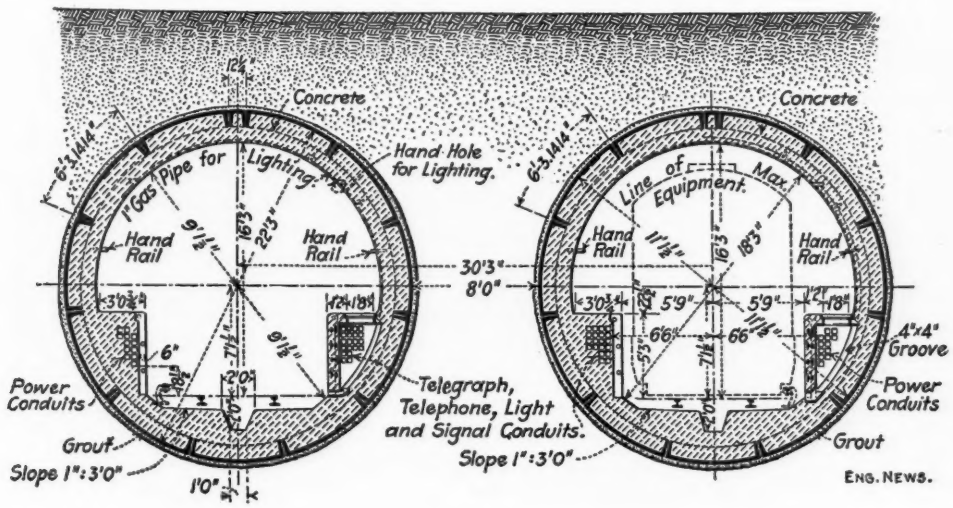


Fig. 7.

CONCLUSION.

The contract plans specify in detail the character of all the material to be used in the work; these specifications conforming closely to the standard specifications of the New York Central & Hudson River R. R. for corresponding materials. Mention may be made of the fact, however, that all mixtures of concrete proposed to be used by the contractor shall be tested by being placed in vessels of the actual water in which its use is planned, where it shall set perfectly before being accepted.

COMPRESSED AIR

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CONTENTS.

Pressure Drop Through Poppet Valves..... 4025
Flow of Air Through Circular Orifices Under Low Heads 4033
A Compressed Air Fire Engine..... 4033
University of Illinois. (Liquid Air Plant) 4033
The Report of the Consulting Engineers for the Panama Canal..... 4034
Proposed Tunnel Under the Detroit River for the Michigan Central R. R..... 4036
Editorials—
"Compressed Air." Subway and Tunnel Work in and About New York Compared With the Panama Canal. Sea Level or Lock Canal. Prof. Hutton Resigns 4044-4046
Western Air Dump Car..... 4047
Westinghouse "K" Feed Valve..... 4048
Vacuum Cleaning Tried in the Subway..... 4049
Correspondence 4050
Jokes With Compressed Air..... 4051
Lubrication of Compressor Valves..... 4051
Practical Items for Practical Men—
Repairing a Cracked Compressor Cylinder. Lubricating With Filtered Oils. A Good Gasket for Steam and Air Cylinder Heads. The Air Pump Strainer. A Good Bearing Metal.... 4052
Chippings..... 4054
United States Patents..... 4056

COMPRESSED AIR

With this number, COMPRESSED AIR makes its appearance in larger and, we trust, more attractive form. It has been the aim of the publishers to produce a magazine which in outward aspect and general makeup would be on a par with the best printed periodicals now published.

The field of compressed air has broadened so materially within the last few years and its uses have become so innumerable that there is ample scope for an enlarged magazine devoted to this subject, and we have endeavored, therefore, to place before our readers a publication which will cover thoroughly the entire field of compressed air in all its applications.

We realize that few people, comparatively speaking, are familiar with the design and operation of compressed air machinery and we hope that our readers will make full use of our columns for the purpose of elucidating any problems with which they may be confronted. COMPRESSED AIR always stands ready to offer assistance in these matters and a discussion of such topics in our correspondence columns cannot but result in benefit to the majority of our subscribers.

SUBWAY AND TUNNEL WORK IN AND ABOUT NEW YORK COMPARED WITH THE PANAMA CANAL

We hear a great deal about the Panama Canal and its difficulties, the popular mind being almost impressed with the idea that these difficulties are insurmountable. The newspapers have almost daily references to the subject and already we have had the suggestion of a scandal. The President of the United States is behind the enterprise. The Panama Canal is frequently referred to as "the greatest piece of industrial engineering work ever constructed." It is not generally understood that work now underway and planned in and about New York for improving railway facilities involves greater engineering difficulties and a larger sum of money than the Panama Canal. This subject was touched upon by Governor Magoun in an interview on the occasion of his recent sailing for the Isthmus, and it is interesting in that the inevitable conclusion is reached that the principal difficulty

at Panama and the reason for so much noise is what Mr. Wallace calls "governmental restrictions." Put the Panama Canal on the basis of New York work and in the hands of competent contractors and it will go along expediously and economically.

On the original Subway so far as completed and put into operation at the end of 1904 the following work was done:

	Cu. Yds.
Earth excavation	2,224,072
Rock excavation	966,777
Tunneling	415,660
Shafts	5,995
Concrete Masonry	586,000
Brick Masonry	36,295
Cut Stone Masonry	29,000
	4,263,799
	Tons.
Steel Erected	68,677
Cast Iron Erected	3,607
	Feet.
New Sewers Built	37,484
Sewers Removed	25,751
Pipes Laid—Water, Gas and Drain.	496,640
Mail Tubes	20,839
Electric Ducts	222,264
Single Track Laid	248,000
Total Value of Work Done	$41,933,000

This not including equipment or operating plant.

At the present writing nineteen other Subway routes have been approved by the Rapid Transit Commission. Five of these will parallel the present Subway; others are crosstown lines or extensions in Long Island and the Borough of the Bronx. There is in sight and reasonably sure of execution in the next fifteen years Subway work which will involve the handling (including that now completed) of over 20,000,000 cubic yards of material and the expenditure of over $200,000,000.

There are at present actually under way, or more or less completed, though not in use, Railroad Tunnels under Manhattan, the North and East Rivers, with extensions and connections in New Jersey and Long Island aggregating over 40 miles in length. Allowing a section of 800 square feet to each single track tunnel this will require the excavation of 6,257,777 cubic yards, which with necessary additional tracks for switching, yarding, express tracks, etc., will easily amount to 10,000,000 cubic yards. The tunnels proposed or planned already more than double this, so that in fifteen years we may assume the work to amount to 25,000,000 cubic yards. The excavation for the P. R. R. and the N. Y. C. stations will require 3,000,000 cubic yards excavation with other roads planning stations in the city, so that if we allow 5,000,000 cubic yards for this work we already have in sight the job of excavating 50,000,000 cubic yards of material under conditions vastly more difficult than anything involved in the Panama Canal job. In addition to this it may be well to keep in mind the vast amount of work involved in a new water supply for the city, which will not be in service before it is urgently needed.

It may be noted that there are now employed in the New York City tunnel work 80 air compressors aggregating 28,000 horse-power, with a free air capacity of 186,000 cubic feet of free air per minute, a volume equal to a cube with a side of 57 feet.

The steam railway work in progress and in sight in and around New York will easily involve the expenditure of $100,000,000, and the new water supply will call for another hundred millions. Mr. George S. Rice, Chief Engineer of the Rapid Transit Commission, has estimated the cost of the proposed new subways of New York at $450,000,000. The estimated cost of excavating a sea level canal at Panama is $183,000,000, so that the expenditure for engineering work in and around New York before the canal is completed will be easily three times as great, while the engineering problems and difficulties will be in comparison even greater than this. There is no apparent reason why success should not ultimately crown all the works in contemplation.

SEA LEVEL OR LOCK CANAL

In the March number of COMPRESSED AIR we discussed the reports of the Board of Consulting Engineers, the majority of whom favored a Sea Level Canal, and the minority an Eighty-Foot Lock Canal. The latter report was accompanied by a letter to Secretary of War Taft from Chief Engineer Stevens endorsing the minority report. This report also had the endorsement of President Roosevelt and was favored by the majority of the American members of the Board of Consulting Engineers. On the other hand, all the foreign engineers and three of the most noted American engineers voted in favor of a Sea Level Canal, and this report was reprinted in full in the *Engineering Record* of February 24th.

Since the rendering of this report, however, there has been under way an investigation by a committee of the United States Senate to

determine, if possible, which would be the better type of canal to built. Much valuable testimony has been given by William Barclay Parsons, C. E., Engineer of the New York Subway; William H. Burr, C. E., Prof. of Civil Engineering at Columbia University, and Alfred Noble, C. E., Chief Engineer of the Pennsylvania Railroad. Mr. Parsons and Prof. Burr are in favor of the Sea Level Canal while Mr. Noble favors the Lock type. Some of the testimony adduced at this hearing brought up points not mentioned in the report. For instance, Mr. Parsons said that if the double gates, proposed by the minority, were to be used, the locks at Gatun would have a usable length of only 790 feet. In order, therefore, to get in the flight of three locks, it would be necessary to reduce the length to less than 1,000 feet, which was decided on by a vote of 11 to 2, by the Board as the *minimum* length. The topography of the country demanded the reduction of the length of the locks if a Lock Canal was to be constructed, and, therefore, three members of the Board reversed themselves in order to sign the minority report. Mr. Parsons stated that ships 900 feet long were in near prospect, and these would require 1,000-foot locks in order to pass through the canal. If a big ship should strike one of the gates he thought everything movable would be carried to the Carribean Sea. The cost of constructing a thousand-foot lock at Gatun would be sufficient to condemn the minority plan even if safety was not taken into consideration. The cost of abutments necessary to support thousand-foot locks at this point had not been estimated since, but it would amount to many millions of dollars.

Mr. John F. Wallace, formerly Chief Engineer of the Canal, also appeared before the Senate committee and presented his views. He also favored a Sea Level Canal, which he believed could be constructed in ten or twelve years and at an expense of about $300,000,000. At least, he thought, the form of canal adopted should be such as could afterwards be transformed into a Sea Level Canal. He gave reasons for believing that the proposed Gatun Dam would in time be found incapable of resisting the strain put upon it. He urged the construction of the canal by contract and favored the immediate reconstruction and modernization of the railroad.

To those of our readers who are interested in this important question of "Sea Level or Lock Canal" we recommend a perusual of the March 29th issue of the Engineering News, which contains Prof. Burr's testimony in full.

PROFESSOR HUTTON RESIGNS

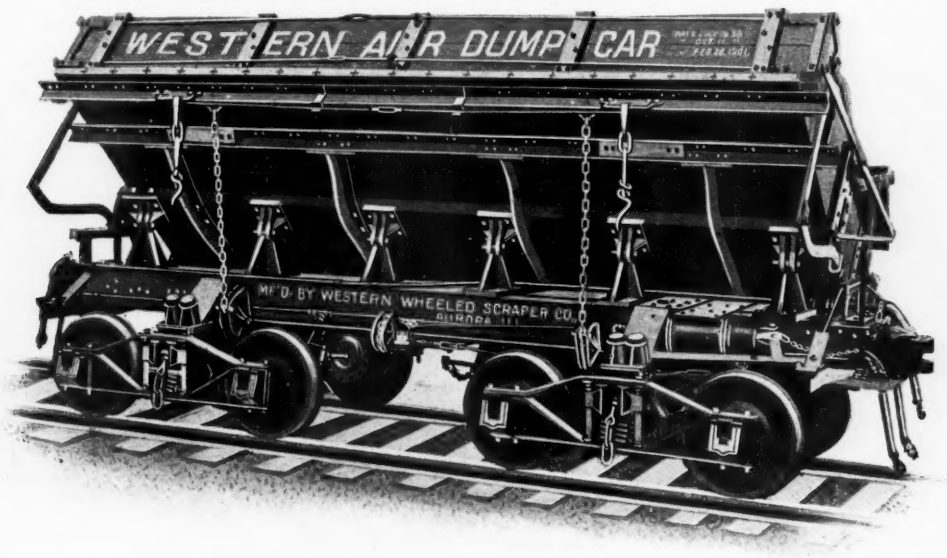
The following letter was sent by Prof. F. R. Hutton to the Council of the American Society of Mechanical Engineers on Jan. 29, but has not been made public until recently: "It may be known to some members of the Council that for several years I have had the thought in mind of resigning the Secretaryship of the Society, on the completion of twenty-five years of service. I was first elected in March, 1883. My more recent thought has been that instead of waiting for a merely sentimental period to elapse, which would have meaning to myself alone, I might rather emphasize the more obvious culmination of my service to the Society by withdrawing at the time when the Society shall cross the threshhold of its new home in the Engineering Building. It will then have been given to me to have wrought for the Society from the days of small beginnings, when I paid my own office rent and expenses, through the period of rented offices, and of the ownership of the modest home in Thirty-first street, and up to the opening of the days of larger opportunity in the splendid surroundings of the new enterprise. It is wise, I am sure, that at the time of this external change the Society should also make the internal change incident to securing as its Secretary one who will and can devote his entire time to the work and development of the Society. It is well known to you that I have felt that I must owe and pay my first allegiance to the work of my professorship in Columbia University. This being the case, the Council should be advised far enough in advance, so that the least embarrassment may be entailed by my withdrawal. I have therefore thought it best to present this formal letter at the first meeting of the year, and to ask by it that proper action may be taken looking to the question for the future which it raises. I ask that I may be relieved of the duties of the Secretaryship at the end of the current society year, or at such other time thereafter as the Council may see fit to have this resignation take effect. It would be

my wish and preference that no unnecessary or premature publicity be given to the fact of my decision. I seek to avoid having anything like a 'fuss' made."

Professor Hutton has been secretary of the Society for twenty-three years. His friends have known that for some time he felt unwilling to continue to hold the office longer, but it has been their wish that he might see his way clear to rounding out a full 25 years' work in this important position. Fortunately a plan has been devised by which the detail executive work can be turned over to a new secretary and Prof. Hutton will act as an honorary secretary, in charge of the meetings and other functions for which his exceptional fitness has long been recognized. To those who have known Prof. Hutton, the amount of work accomplished by him has seemed phenomenal. Not only has he brought the American Society of Mechanical Engineers to the enviable position in which it now stands, but he it is who has directed as Dean the Schools of Engineering at Columbia University during their unprecedented growth of the last few years. Prof. Hutton, notwithstanding his multiplicity of duties, has found time to write numerous engineering works, of which his "Mechanical Engineering of Power Plants," "Heat and Heat Engines" and "The Gas Engine," are considered authorities in their respective subjects. While the American Society of Mechanical Engineers loses a most valued executive, Columbia University is to be congratulated upon securing the undivided services of its Professor of Mechanical Engineering.

WESTERN AIR DUMP CAR

The enormous amount of earth handling involved in prosecuting the line and terminal improvements which railways have so extensively undertaken within the past few years has necessarily caused a considerable evolution in the methods and equipment whereby this work is accomplished. Prominent in this equipment is the dump car and its evolution has been marked in many respects. A well-known example to which these remarks apply is noticeable in the latest type of dump car manufactured by the Western Wheeled Scraper Co., Aurora, Ill.



WESTERN AIR DUMP CAR.

While the steps of evolution mentioned might be of interest to those who have not been intimately connected with the development of earth handling methods, those to whom the subject is of most interest, are so familiar with the past progress that it will probably be best to only deal with the present modern example. This is the car whose capacity has been increased to 12 cubic yards, or 16 yards when heaped. A number of this de-

sign were furnished the Isthmian Canal Commission, and are now in operation on the Isthmus of Panama.

The features of construction are readily noted in the illustration, but it may be remarked that it is an all-steel construction, including the center sills, in which wood finally succumbed to steel because of the increase in capacity of the car and the air dumping feature. The general construction is the same as that of the smaller sized cars, constructed under the same patents, *i. e.*, they are provided with the automatic pivoted side board and loose pin and socket hinge on which the bed rests. The discharge opening is extremely large on account of the side boards being thrown upward and outward from the bed, so that there is ample clearance for large boulders or masses of frozen earth. The dumping angle is very steep—forty-seven degrees—which enables the car to clear itself without hand shoveling and yet to throw the load far from the track, an appreciated feature in heavy work.

There is a patent pending on the air pumping device, the dumping as well as the bringing of the bed back to loading position being controlled from the engine by means of compressed air. The air dumping mechanism consists of a cylinder and set of levers, chains, shaft and cams for each side. The thrust of the cylinders acts on the lever, which transmits the motion to a shaft through a chain operating over a cam. On the same shaft are two other cams to which the dumping chains are attached. The latter are also fastened to the outer angle sill on the bed. The action of the lever causes the shafts to rotate, drawing the bed down to the dumping angle and back to an upright position. This device has passed the theoretical stage and the air dump cars are in practical use and are being operated with entire success, as is proved by the immediate large demand for this design.

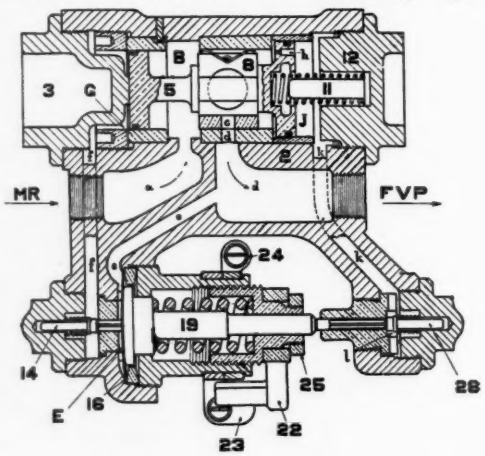
THE WESTINGHOUSE "K" FEED VALVE

The improved feed valve shown in the illustration is the latest, and the one now being supplied with the new ET engine and tender equipment.

Its inner construction is easily understood from the drawing which is a diagrammatic view of the valve in the open position.

Its operation is as follows: Main reservoir air enters at the connection marked "*MR*," passes through port *a* into chamber *B*, between the heads of the differential piston 5; then through port *c*, in the slide valve 8, to port *d* in its seat and to the connection marked *FVP*, the feed valve pipe, which goes to the brake valve and through passage *e* to chamber *E* and the diapraghm 16; then past valve 14 to passage *f* and chamber *G*, behind the smaller head of the differential piston.

At the same time, the air also passes through port *h* in the larger head of the differential piston into chamber *J*, and on through passage *k* to chamber *l*, in which the small vent valve 28 is located. The air and spring pressure hold valve 28 to its seat while diaphragm



spindle 19 is in the position as shown. While the slide valve 8 is in "open position," supplying air to the brake pipe, the pressure in passages *e*, *d*, *k* and in chamber *l*, will be the same in amount up to the point for which the feed valve is adjusted.

When the pressure in chamber *E* over the diaphragm 16 and regulating spring surrounding diaphragm spindle 19, reaches the limit of adjustment it will compress the regulating spring and force the diaphragm spindle 19 to the right far enough to press against the guide stem of vent valve 28, and unseat this valve.

When valve 28 unseats, the air in chamber *l*, passage *k*, and chamber *J*, will escape to the atmosphere, thus quickly reducing the pressure behind the larger head of the differential piston.

With the pressure thus reduced in chamber

J, main reservoir pressure. in chamber *B*, assisted by brake-pipe pressure in chamber *G*, will force the differential piston 5 and the slide valve 8, which is caught between the shoulders on the valve stem connecting the piston heads, to the right quickly and close the communication between the main reservoir and the brake pipe, thus preventing further increase of pressure in the latter.

When the diaphragm 16 and the diaphragm spindle 19 are forced to the right, in the manner described, the small valve 14, previously held from its seat, permitting communication between chambers *E* and *G* and the brake pipe, seats, and cuts off this communication.

As soon as brake pipe pressure falls below the limit of adjustment, the diaphragm 16 and the diaphragm spindle 19 move to the left, unseating valve 14 and permitting the air in chamber *G* to flow through passage *f* and chamber *E* to the brake pipe, and seating valve 28, permitting pressure to accumulate behind the larger head of the differential piston. Then piston 5 moves quickly to the left, and opens the feed port *d* to the brake pipe.

The regulating spring is a short one, and the regulating nut has a handle fitted to it so that when this handle is against the stop 23, which is mounted on the spring case, the feed valve will maintain 70 pounds pressure in the brake pipe; when the handle is moved around to the stop 24 the feed valve will maintain 110 pounds brake pipe pressure. By changing the location of the stops any intermediate brake pipe pressure between 70 and 110 pounds may be had.

Because of the quick and simple method of changing from one pressure to another, as required by the kind of service in which the locomotive is employed, but one feed valve of this tvpe used in conjunction with the improved pump governor, is necessary on any engine, passenger, freight or switcher. Hence, in changing from the low pressure to the high pressure control, or the high speed brake, it is only necessary to change the position of this regulating handle from one stop to the other.

VACUUM CLEANING TRIED IN SUBWAY

Interborough Makes Practical Test of System at Worth Street Station

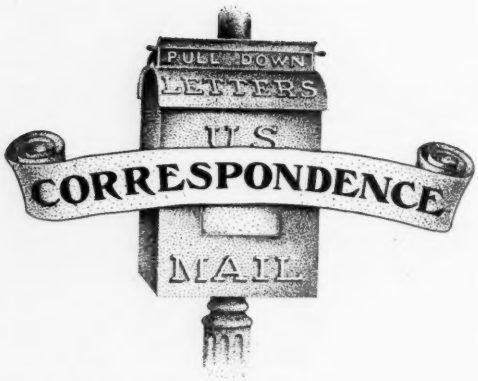
In the presence of a representative of George H. Pegram, electrical engineer, and other officials of the Interborough system, a practical demonstration of the vacuum system of cleaning, which is the application to sanitary and commercial uses of the principle of the vacuum, was made at the Worth street station of the subway.

The work under the direction of C. A. Benton and John M. Moynihan, was done by the introduction of one of the company's portable wagon plants, which consists of a gasoline motor, and vacuum hose, through which the dust, microbes, insects and disease germs are extracted and drawn to the sanitary piping, and thence to the separator tanks, consisting of two upright cylinders. The first of these separates from the air current the process of separation by passing the air current through a column of water in which the remaining matter is held in liquid suspension. By means of renovators attached to long handles, the platforms of the station, the side walls, the iron columns and a portion of the ceiling were quickly and thoroughly cleaned. A well kept church in New York, it is said yielded under the vacuum process 790 pounds of black worldly dust, and a scrupulously kept dining room in a private house confessed to 12¾ pounds of dirt.

It was shown that a car fitted with the apparatus, running on the tracks, could clean a station in half an hour, and remove all the dirt to the terminal. The Central Railroad of New Jersey has a stationary plant that carries cigar stubs and papers half a mile through its tubes. A more exhaustible trial will be made in the subway soon.

A WESTERN contractor seems to have hit upon a most unique scheme for digging the Panama Canal. He proposes to let loose 500.000 woodchucks on the line of the canal. After the woodchucks have become well holed, he would let loose 250,000 muzzled farm dogs to dig them out again. With the woodchucks scratching the dirt to get away from the dogs, and the latter digging lustily to catch the woodchucks, the contractor figures that a large amount of the excavation would be accomplished in a short time.—*Roadmaster and Foreman.*

Why not use compressed hares ?



To the Editor of Compressed Air.

DEAR SIR:—In your issue of January, page 3861, Mr. Edward F. Schaefer gives the following simple formula for obtaining the atmospheric pressure in pounds per square inch at any elevation, viz.:

$$P = 14.75 - \frac{57000\ E - E^2}{100{,}000{,}000}$$

As the originator of the formula, I would like to state that it appeared over my signature in your issue of October, 1897, page 317, but with the added information that "it was original and, needless to add, an empiric one. This formula gives results in some cases varying about one-sixth of one per cent. from certain published tables, but it has the advantage that when plotted it gives a *perfect* curve, which no table that I have seen will do." I think your readers should know that this is an empiric formula, and not the standard one deduced from scientific observations and mathematical calculations.

Very truly yours,

WILLIAM COX.

To the Editor of Compressed Air.

Dear Sir:—In the January issue of COMPRESSED AIR there appeared a short article on Altitude Atmospheric Pressures in which a table and a curve are found. You will notice that no claim is made that the formula is original. For my own use I deduced the table, using Cox's impirical formula, and plotted the curve. As these were of assistance to me I gave them to COMPRESSED AIR suspecting that the readers might find use for them. Very truly, EDWARD F. SCHAEFER, M. M. E.

To the Editor of Compressed Air.

Dear Sir:—I have under contemplation the installation of a 5-inch air pipe line about 8,000 feet long, partly in a mine tunnel and largely out of doors on the surface of the ground. I am contemplating using 5-inch bell and socket pipe with lead joints, the same as are used for water pipe. Can you tell me whether such pipe has ever been used for the purpose, and if so, whether there was any objection found to its use. Any information which you can supply along these lines will be very thankfully received. Very truly yours,

J. E. JOHNSON, JR.

THE only case that has been brought to our attention where bell and socket pipe with lead joints has been used for conveying compressed air is that at the building of the Washington Aqueduct Tunnel in Washington, D. C., some fifteen years ago, and we distinctly recall that there were so many difficulties involved in the use of this pipe for compressed air purposes that we have since advised against it.

In the case referred to the pipe was laid on the surface of the ground and subject to expansion and contraction, due to sun, rain, etc., so that the leakages were very serious. We can quite understand a case where the pipe may be laid underground and in that way a more or less uniform temperature be maintained. In a case like this the difficulties may be minimized, but generally speaking we would advise against the bell and socket joint for compressed air transmission.

To the Editor of Compressed Air.

Dear Sir:—I have a windmill and have wondered if I could not compress air with it and use it for electric lighting and other purposes. Sincerely, WILBUR L. GILLETTE.

WHILE windmills, as far as we can determine, have very rarely been used for compressing air, there is no reason, however, why they should not be adapted to this purpose. A windmill with a twelve foot blade is commonly rated at two horsepower and one with a sixteen foor blade is rated at four horsepower. If this power were utilized for compressing air, the results obtained would be as follows:

2 h. p. will compress 9.6 cu. ft. of free air per min. to 100 lbs. gage.

2 h. p. will compress 11. cu. ft. of free air per min. to 80 lbs. gage.

4 h. p. will compress 19. cu. ft. of free air per min. to 100 lbs. gage.

4 h. p. will compress 22. cu. ft. of free air per min. to 80 lbs. gage.

The above results were calculated on the assumption that 15 per cent. be allowed for friction in the air compressing machine, but probably for an apparatus of this kind a greater allowance should be made. As large a receiver as possible should be used to take care of the intermittent nature of the power supply.

The ideal way of utilizing wind-power for the compression of air would be to operate a high-pressure compressor for this purpose, in order that a large quantity of air might be stored in a small sized receiver. Then, by operating the windmill all night, sufficient quantity of air might be stored up to run pneumatic tools during part of the day.

It is not practicable to use wind-power for the generation of electricity.

JOKES WITH COMPRESSED AIR

Press despatches contain an account of the death of a boy employed in the works of the Cambria Company, at Johnstown, Penn., whose death was brought about by means of compressed air injected into his viscera by a workman who was in a playful mood. This is the second so-called accident of that nature which has come to our notice, the previous one occurring, we believe, in Paterson, N. J. It is high time, it seems to us, that those who have to do with compressed air should know that it is a thing not to be trifled with. We have a letter from an employer in whose shop compressed air is used, and he expresses it as his opinion that those who attempt practical jokes with compressed air should be severely dealt with. In his own shop, all employees are warned as to the danger of attempting to play any practical jokes with compressed air, and he believes that something of the kind should be done in every establishment in which it is used.

A. E. Hoermann, 41 Park Row, New York City, is distributing in the Eastern States a catalogue of the Pilling Air Engine Company, of Detroit, which company they represent. This catalogue shows pneumatic motor hoists, pneumatic engines with various applications, and also the pneumatic turn-table devise. Any parties in the Eastern States who wish to have one of these catalogues will kindly send in their name.

LUBRICATION OF COMPRESSOR VALVES

VALVES which stick con often be successfully lubricated and kept in good condition by use of a little kerosene oil, applied with the usual machinery oil can.—*Mining & Scientific Press.*

We quote the above paragraph to show how some people may be misled regarding the handling and care of air compressors, and because we believe that such articles as the above are often responsible for serious accidents. Kerosene oil ought never to be used in this way, and if used at all on the air cylinder, great care should be taken to remove all of it before starting up the compressor. A much better and safer way of cleaning the cylinder and valves is to feed orginary soapsuds through the cylinders for several hours every week or two. It may be passed through the lubricator instead of oil, but care should be taken to run with oil for a while after its use, before shutting down, in order to prevent rusting.

It is a very good practice to keep an extra set of outlet valves on hand, as this enables the engineer, at any time, to replace those on the compressor with clean ones. The change may be accomplished in a very few minutes and the dirty valves may be thoroughly cleaned by the engineer at his leisure.

ACCORDING to Mines and Minerals compressed air is used to operate a novel device for dumping ore cars at the Cactus Mills, Newhouse, Ntah. In the mine the ore is loaded from chutes, with pneumatically operated doors, into mine cars of four tons capacity. A train of fourteen to twenty-one care is then pushed by an electric locomotive to the ore bins at the tunnel entrance. Here over the bins is an unique dumping device in the shape of a hollow steel cylinder open at the top, set on wheels and of such size as to hold seven cars in a close fit by angle irons set over the upper edges of the box. The cars are run into the cylinder, seven at a time, the motor uncoupled and the cylinder revolved by a compressed air engine. In this way twenty-eight tons of ore are dumped in thirty seconds actual time from the uncoupling to the recoupling of the motor.

PRACTICAL ITEMS for PRACTICAL MEN.

REPAIRING A CRACKED COMPRESSOR CYLINDER

The loosening of one of the discharge valve seat bushings, which worked through and dropped into the cylinder before it was detected, resulted in the cracking of a compressor cylinder of 16 inches in diameter. It was repaired in the following manner. A radial slot 1½-inch wide was cut to the full depth of the flange, about 4 inches on each side the crack in the cylinder, as shown in Fig. 1, where the worst leak occurred, and carefully finished on the side adjacent to the crack.

A link was then made of 1½-inch square

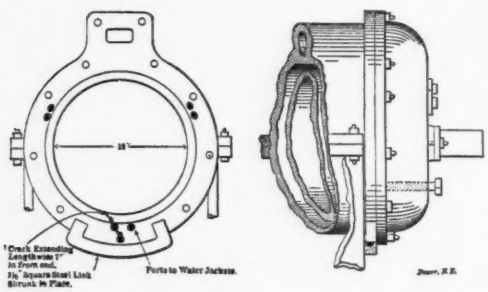


Fig. 1.

steel and curved to the shape of the flange, with the ends forged outward to correspond with the slots, and carefully finished on the inner sides, so that it lacked entering the slots by about 1-64-inch more than the width of the crack, as nearly as could be determined.

A ⅜-inch hole was drilled, tapped and plugged at the end of the crack to prevent it from "growing."

Next the link was heated to a fair red heat so it would enter the slot easily, after which a cement was rubbed in to make a rust joint in the crack. When the cement had cooled the crack could hardly be detected and was perfectly tight.

The cylinder head, which was cracked at the same time, was remedied by drilling and tapping a ⅞-inch hole through the water jacket and forcing the metal back nearly to its original position, by screwing a bolt with a long thread through the jacket and against the head proper, and then applying a liberal amount of the same cement. This is shown in Fig. 2.

The loss of the valve seat bushing, which was demolished in the cylinder, necessitated

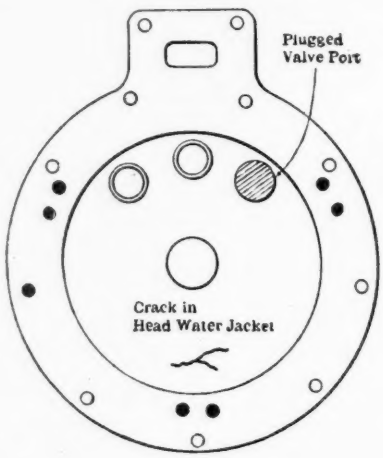


Fig. 2.

the tapping out of the hole with 2½-inch pipe tap and screwing in a plug which was trimmed off flush with the inside of the head, which left two valves to discharge the air from that end. The plugged valve port is shown in Fig. 3.—*H. R. M., in Power.*

LUBRICATING WITH FILTERED OILS

The great difference in oils makes it necessary for the engineer, who desires to obtain the best service with the least amount of oil, to make a careful study of lubrication. For instance, in air compressors, a light oil is most suitable for the air cylinders because of its less liability to carbonize, but, for steam cylinders, we require an oil of greater viscosity and a higher fire test. The greater part of engine oils are a trifle too light to thoroughly coat the bearings and remain long enough to do good work in lubricating. In Summer, these light oils have little capacity for absorbing heat.

My experience with filtered oils has been obtained in a plant containing five engines, all of which are compound, and two of which drive air compressors, while the other three drive electric units. I use a light grade of oil for the air cylinders and a good grade of cylin-

der oil in the high-pressure steam cylinders. For lubricating the low-pressure cylinders, I use the droppings from the high-pressure pistons, cross-heads and wrist pins, which oil, after being filtered, does good service in these cylinders and also in the boiler feed pump. I have enough of this filtered cylinder oil left to make a good mixture with the filtered engine oil and thus improve its quality. I find that it requires less of the filtered and mixed oil than of fresh engine oil to do the same amount of lubrication.

In carrying out this plan, I used two 60-gallon tanks and two good filters, one for the cylinder oil and the other for the engine oil. Each day the oiler gathers up all the droppings and places a small amount of fresh engine oil in the engine oil filter, together with about half the same amount of filtered cylinder oil. After passing through the filter, this mixture comes out in the form of an extra fine engine oil of dark color, having all the requirements for successful and economical lubrication. This oil can be used over several times by replenishing each time from the light engine oil and from the filtered cylinder oil. The daily consumption of oil is measured by the amount of fresh oil that is supplied to the filtering tank each day.

Care should be taken to select good mineral oil which will blend well and filter. Cheap oils will not blend and are the most expensive in the end. Oils containing animal fats, or other substances, should not be used on high-speed engines under any circumstances.—W. D. RANNEN, *in The Engineer.*

A GOOD GASKET FOR STEAM AND AIR CYLINDER HEADS

A very serviceable gasket may be made easily and cheaply by the following method: Ordinary heavy Manilla wrapping paper should be cut out to the shape of the cylinder end by the ordinary method of cutting gaskets. This paper should then be soaked in boiled linseed oil for a few minutes and then have manganese dioxide applied to it with a paint brush, the linseed oil mixing with the manganese dioxide forms a black paint over the surface. The gasket should then be put on while wet and will form an exceedingly durable and efficient gasket for the cylinders of steam engines or air compressors.

THE AIR PUMP STRAINER

On one of our leading eastern trunk lines frequent reports came into the round house that the air pump would not pump a sufficient amount of air to supply the train, and upon one occasion a pump was condemned and changed, although there was no apparent reason for condemning the pump, other than it would not supply enough air.

Following this instance another of the same nature occurred, in which it was found that the strainer was at fault, it being almost entirely plugged.

These instances woke me up to the fact that a plugged strainer is a serious defect, in that if a pump cannot get air, it certainly cannot compress air; hence we have no air at all or only a meager supply for the air brake system.

I find it very profitable to myself and all concerned to keep pump strainers free from all dirt, and especially valve oil. Since the strainer is for the purpose of excluding all foreign matter, and to freely admit air, the air cylinder should never be oiled through it, but through the oil cup which is provided for that purpose.

A very effective and speedy manner of cleaning strainers is to blow steam through them; the steam loosens any crust formation due to dust, etc., and also increases the temperature of any valve oil that may have been wrongfully poured over the strainer, so it will run freely.

Any air brakeman who will keep the air pump strainer clean and the meshes open and the pump in good repair generally, by well lubricating it and tightening all leakages of both steam and air, will save himself much unnecessary work and trouble, and will also save the railroad company, that employs him, many pump failures and consequently engine failures, which will surely be appreciated by them.—*Wirt D. Seely in Railway & Locomotive Engineering.*

A GOOD BEARING METAL

A mixture consisting of 50 per cent. aluminum, 25 per cent. zinc and 25 per cent. tin forms an alloy which is excellent as a bearing metal. It is light in weight, has a fair degree of hardness and a moderately high melting point

CHIPPINGS.

IN forging rock-drill bits those for medium hard rock should have sharp chisel bits. As the hardness of the rock increases, the angle of the bit may be made more blunt, and the cutting edge shaped from a straight line to a curve, to prevent the corners being chipped off.

When drilling in sandstone the drill-bit should be tapered somewhat and then flattened instead of drawn to a cutting edge. If a chisel-bit is used in drilling sandstone the bit will wear very sharp, and will frequently become fitchered.

For fast cutting in drilling, the straight chisel-edged bit is recommended. This style of bit must be carefully tempered, as the cutting is mostly done by the sharp corners, which are likely to be chopped off if there is the slightest flaw. The hammer blows should be sharp and quick. In hard rock a somewhat rounded and rather blunt bit is more economical, though it will not, perhaps, cut so fast.

Many tests have been made to ascertain the conditions under which mixtures of air and fire damp become inflammable or explosive. Mixtures of fire damp and air, which are not ignitable by an open light, often ignite or become explosive on addition of a little coal dust, and mixtures which will not ignite on application of a flame of small intensity will do so when a flame of strong intensity is applied to them.

Compressed air employed as motive power in collieries at a distance from the shaft bottom is theoretically less efficient than electric transmission, on account of the thermo-dynamic loss of available energy. There is often a large leakage of air in long pipes. One of the chief advantages arising from the employment of compressed air plants in coal mines is security from dangerous accidents.—*Engineering and Mining Journal.*

With a 3⅛-in. drill, using air at 70 pounds, pressure, starting bit 2¾ in., and finishing bit 1½ in., the time required to drill 1 foot is about 3 minutes in soft sandstones and limestones, 4 minutes in medium sandstones and limestones, 5 minutes in hard granites, hard sandstones, etc., 6 to 8 minutes in very hard granites and traps, and 8 to 10 minutes in soft rocks that sludge rapidly. It is especially noteworthy that if a water-jet be not used, drilling in a soft, friable rock like shale may be slower than in the toughest trap.—*Engineering and Mining Journal.*

The chief cause of knocking out a machine and breaking, bending and blunting drills is carelessness and the lack of supervision while starting holes. It is also contended that in actual practice nearly 40 per cent. more work can be done in a given time with the air pressure, in underground machine boring in ground of the average hardness, such as is found in the Transvaal, at 80 pounds instead of at 60 pounds. In West Australia 100 pounds pressure has been kept on the receiver when working in hard quartz. A mistaken desire for economy may induce the miners or the pipe repairer to use worn out piping and hose for connections, which, of course, leads to frequent stoppage and to a more or less constant loss of air by leakage.—*Mining World.*

The Chicago Pneumatic Tool Company has closed its Norfolk office, which was located in the Chamberlaine building, and will in the near future open an office in Richmond, Va. The office located at 602 Empire Building, Pittsburgh, Pa., will be moved April 1 to 10 and 12 Wood street, at which point a store building has been secured for the purpose of making a general display of air compressors, tools, &c., a large stock of which will be carried as soon as the factories are in position to furnish it, and a well-equipped repair department will also be maintained for the benefit of the company's large number of customers in the district. The office has been closed at Seattle, Wash., and a new office opened at 84 Sixth street, North Portland, Ore. The company reports business entirely satisfactory both at home and abroad, all factories working double time.

The Westinghouse Machine Co. filed a bill of complaint on February 9, in the Circuit Court of the United States, for the District of New Jersey, against the Allis-Chalmers Co., alleging that the Allis-Chalmers Co., in the manufacture and sale of its turbine, is infringing patent No. 655,414. issued to Mr. Charles A. Parsons, August 7, 1900. This invention was made jointly by Parsons, Steney and Fullagar, and is for steam turbine ring of blades covering the method of construction used by the Allis-Chalmers Co., for securing the blades and vanes in place in their respective holding elements. An assignment of the entire rights under this patent was secured by the Westinghouse Company from Charles A. Parsons on January 10, 1905, both Steney and Fullagar having assigned their interest in the same to Parsons prior to the issuance of the patent.

The following general criticism of American technical books is taken from Indian Engineering, and is, we regret to acknowledge, too frequently true to be successfully disputed: "The fourth edition of ———, by———, C. E., published by Messrs. ——— of New York and ———, of London, is another of those American books on engineering which are crammed full of general information, but which are sadly lacking in details. The information contained in the 550 pages is varied, but there is not enough of any particular subject. This lack of detailed information is a great feature of the American scientific literature of our day. It seems as if one class of men designed and carried out the works, and quite another class wrote about them. What the world wants are books written by the men who have designed and carried out the works which are being described. Such books can best help those who are being called upon to design and construct." This subject "is so interesting and so original that we want to know more about it than such books tell us. Pracical men working in the country want more detailed information than suffices for students at college."—*Railway and Engineering Review.*

We think this criticism applies particularly well to some of the books which have been written on compressed air in all its applications.

The Associated Mines, at Kalgoorlie, Western Australia, have a large air compressor, designed for 60 drills, and stated to be able, with an expenditure of 1,000 horsepower, to compress 5,000 cubic feet of free air per minute. According to the returns made by the manager, the amount of air ordinarily put into the underground workings is 1,700 cubic feet of free air per minute, which supplies 20 drills and two air winches, while about 100 cubic feet per minute are used in driving pumps. Taking the winches as using 300 cubic feet per minute, and neglecting leakages, the amount supplied to each drill would average 65 cubic feet per minute. The number of men underground is returned at 292, or, say, 100 men in one shift. The total amount of air per man put into the mine by the compressor therefore only averages 17 cubic feet per minute. Taking the men on the drills only, each drill having two men, the quantity per man averages 32½ cubic feet per minute. As each drill when actually working probably liberates over 100 cubic feet of air per minute, the average of 65 cubic feet must be much higher than the amount set free while the drill is not working, and the amount supplied to the men while setting up the machine must be very small. Usually the air is used for blowing out the smoke, and then is cut off, or almost so, while the men rig the drill. During this period the ventilation is often very deficient. Analyses made by Mr. Mann show that even when the drills are running, there are places where the ventilation is bad.

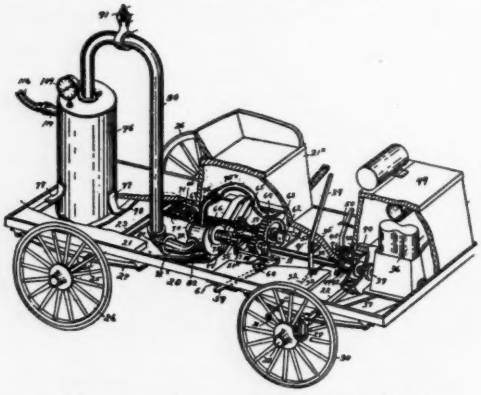
The Commissioners do not wish to be understood to mean that in the instance quoted and in similar cases the only ventilation in the mine is that from compressed air, for, as a matter of fact, the principal air supply to these mines is obtained from natural ventilation. The figures quoted were meant to show that the compressed air by itself is a quite insufficient supply, and would not alone be able to maintain the air in a pure state. Usually, there is a certain amount of air from the main airways slowly finding its way into even such places as are some distance from the main aircurrents, and gradually removing the vitiated air.—*From Report of Royal Commission, Western Australia.*

U. S. PATENTS GRANTED MARCH, 1906.

Specially prepared for COMPRESSED AIR.

814,837. **Pneumatic Dust Removing and Collecting Apparatus.** Ephraim H. Fenton, Kansas City, Mo. Filed Nov. 8, 1904. Serial No. 231,948.

Claim.—1. In a pneumatic, dust-collecting apparatus, the combination with a vacuum-tank and conductors for the dust leading to the tank, of inclined, dust-deflecting plates within said tank, an air-suction apparatus connected with the tank, and a rotary separating-



fan within the tank, energized by the air entering and passing through the tank.

2. In a pneumatic, dust-collecting apparatus, the combination with a vacuum-tank for the dust, and with a conductor for the dust leading to the tank, of dust-deflecting plates within said tank, an air-suction apparatus connected with the tank, a rotary fan within the tank actuated by the air entering and passing through the tank, and means between the suction apparatus and the entrance to the tank self-acting to regulate the exhaust from the tank.

3. In a pneumatic dust-collecting apparatus, the combination with a vacuum tank for the dust and with a conducting-pipe for the dust leading within the tank, of a suction-pipe leading within the tank and terminating in a downwardly-extended, outwardly-flaring end, an air-suction apparatus connected with the suction-pipe, and means in said pipe for regulating the exhaust in the tank, dust deflecting devices within the tank, and a rotary fan intermediate the outwardly-flaring, downwardly-extended end of the suction-pipe and the dust-deflecting devices.

814,983. **Pneumatic Hammer.** Rheinold A. Norling, Aurora, Ill., assignor to Aurora Automatic Machinery Company, Aurora, Ill, a Corporation of Illinois Filed May 31, 1905. Serial No. 263,077

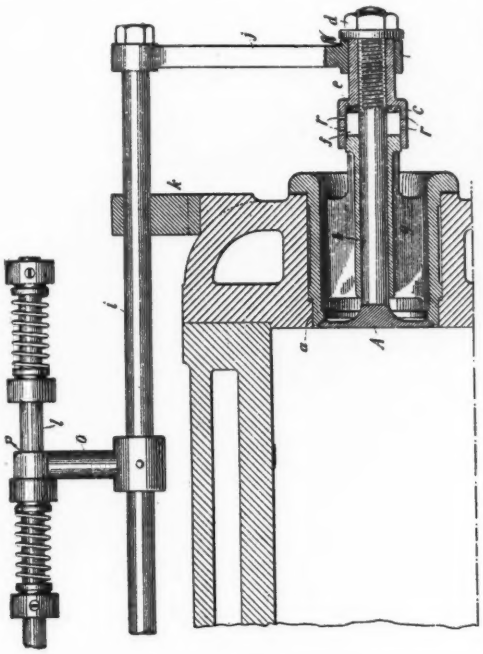
Claim.—1. The combination with a cylinder and a plunger therein, of a live-air-actuated controlling-valve and an auxiliary valve, operated by air compressed within the inner end of the cylinder in the backward stroke of the

plunger, for controlling the admission to the controlling-valve of air to acutate the said controlling-valve.

2. The combination with a cylinder and plunger therein, of a controlling-valve for controlling the admission and exhaust of air into and from the cylinder, embracing a valve-piston having two faces of different areas, means controlled by the plunger for admitting live air to act on the larger face of said valve-piston, and an auxiliary valve controlling the admission of live air to act on the smaller face of the said piston, said auxiliary valve being operated by pressure of air compressed in the inner end of the cylinder in the backward stroke of the plunger.

815,488. **Valve for Air Compressors.** Thomas S. Sturtevant, Dover, N. J., assignor to McKiernan Drill Company, Dover, N. J. Filed Apr. 9, 1903. Serial No. 151,849

Claim.—1. A valve mechanism for air-compressors comprising a valve, a valve-stem, and a valve-stem journal, said valve provided with air-cushioning means for retarding the

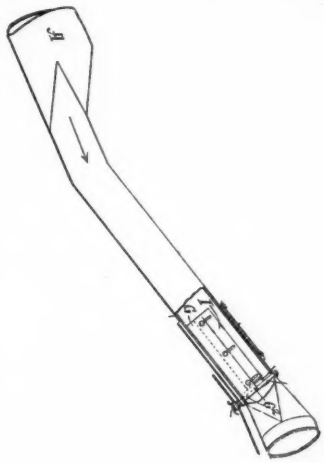


opening thereof, comprising a cylindrical sleeve on the valve-stem and a co-operating abutment on the valve-stem journal, a tappet or operating rod, a connecting-rod having a yielding connection with the operating-rod and an operating connection between said connecting-rod and valve-stem, whereby the connecting-rod has a free movement in one direction without operating the valve.

2. A valve mechanism for air-compressors comprising a valve, a valve-stem, and a valve-stem journal, said valve provided with air-cushioning means for retarding the opening thereof, comprising a cylindrical sleeve on the valve-stem and a co-operating abutment on the valve-stem journal, a tappet or operating-rod, a connecting-rod, a link or arm on said connecting-rod having a sliding connection with said operating-rod, cushioning-springs on said operating-rod upon opposite sides of said link connection, and a second arm rigidly secured to said connecting-rod and having a sliding connection with said valve-stem whereby the connecting-rod has a free movement in one direction without operating the valve.

815,965. **Pneumatic Conveying Apparatus.** Arthur C. Lynch, Richmond Hill, N. Y., assignor to Sterling Blower & Pipe Manufacturing Company, New York, N. Y., a Corporation of Connecticut. Filed Aug. 7, 1905. Serial No. 272,969.

Claim.—1. In pneumatic apparatus for conveying shavings, &c., a main conduit having a conduit-section with a floor inclined to the direction of travel in said main conduit and branch passages leading from the upper end thereof, in combination with a movable de-

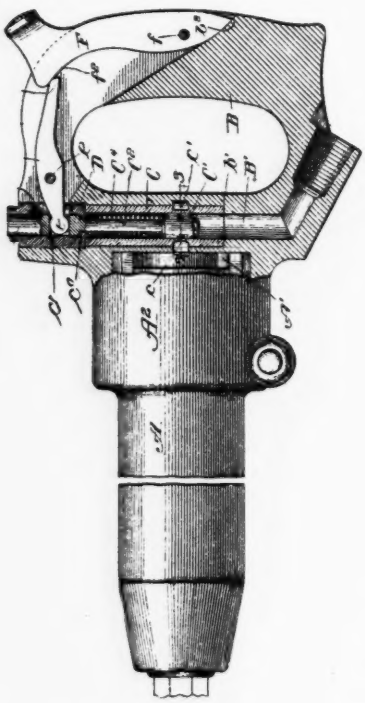


flecting-partition of less height than said conduit-section, located nearer the said inclined floor than to the top of the conduit-section, so as to provide a space for the passage of air above said partition, and adapted to determine the relative deliveries of shavings into said branch passages.

2. In pneumatic apparatus for conveying shavings, &c., a main conduit having a conduit-section with a floor upwardly inclined with respect to said main conduit and branch passages leading from the upper end thereof, in combination with a dividing-valve of less height than said section, pivoted at the junction of the branch passages to swing over and in proximity to said inclined floor, whereby an open space is left above the valve for the passage of air into said branch passages.

816,246. Throttle-Valve for Pneumatic tools. Reinhold A. Norling, Aurora, Ill., assignor to Aurora Automatic Machinery Company, Aurora, Ill., a Corporation of Illinois. Filed Feb. 24, 1905. Serial No. 247,143.

Claim.—1. A throttle-valve comprising a cylindric valve-chamber provided with a lateral port, a sliding valve-piston in said valve-chamber, a valve-stem connected with the piston, said piston being provided with an aperture to receive the valve-stem, a nut adjustable on the valve-stem to change the position of the valve-piston on the stem, and a spring applied to hold the valve-piston against said nut.



2. A throttle-valve comprising a cylindric valve-chamber provided with a lateral port, a sliding valve-piston in said chamber, and an endwise-movable valve-stem connected with the valve-piston, said valve-piston being provided with a central aperture to receive the valve-stem, a nut adjustable on the valve-stem to change the position of the piston on said stem, and a coiled spring surrounding the valve-stem and acting on the valve-piston both to hold the said valve-piston against the nut and to give endwise movement to the valve piston and stem.

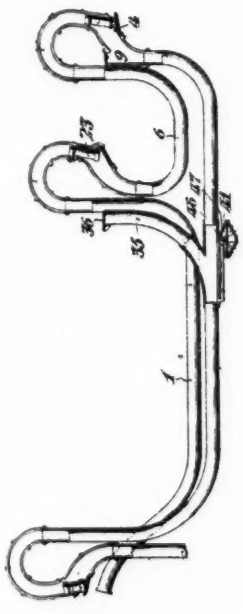
3. A throttle-valve embracing a cylindric valve-chamber communicating at one end with an inlet-passage and closed at its opposite end, said valve-chamber being provided between its ends with a lateral exit-port, an endwise-sliding valve-piston in said chamber adapted to cover said port when advanced toward the inlet-passage and to uncover said port when retracted toward the closed end of the chamber, and a valve-stem connected with the piston and extending outwardly through the closed end of the valve-chamber, said valve-piston being provided with a passage for the leakage of air therethrough to the closed end of the valve-chamber to balance the valve.

4. A throttle-valve comprising a cylindric valve-chamber communicating at one end an inlet-passage and closed at its opposite end, a sliding valve-piston in said chamber, and an endwise-movable valve-stem connected with the valve-piston and extending outwardly through the closed end of the valve-chamber, said valve-piston being provided with a central aperture for the valve-stem, larger in diameter than the portion of the stem which passes therethrough, a nut on the valve-stem, and a spring applied to hold the valve-piston in contact with said nut.

5. A throttle-valve comprising a cylindric valve-chamber communicating at one end with an inlet-passage, closed at its opposite end and provided with a lateral exit-port, a sliding valve-piston in said valve-chamber, a valve-stem connected with the piston and extending through the closed end of the valve-chamber, said piston being provided with an aperture to receive the valve-stem, and the valve-stem being provided with a nut adjustable thereon to change the position of the valve-piston, and a spring applied to hold the valve-piston against said nut, the central opening in the valve-piston being larger than the part of the valve-stem which passes through the same and said nut being provided with a notch which forms with the space between the valve-piston and the valve-stem, a passage to permit leakage of air past the piston to balance the valve.

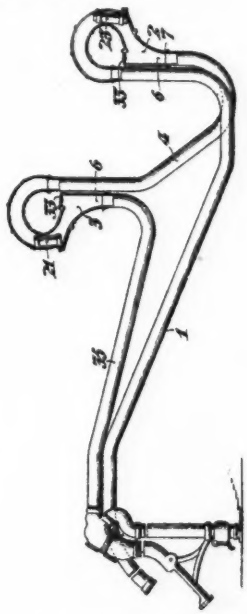
6. A throttle-valve comprising a valve-casing provided with a cylindric passage opening at both ends through the sides of the casing and with one end of which is connected an air-supply pipe, said passage having a shoulder at its inlet end, a cylindric valve-bushing seated in said passage, and bearing at its inner end against said shoulder, said bushing having a lateral exit-port and forming a valve-chamber which communicates at one end with the inlet end of said passage, a hollow plug secured in and closing the end of the passage remote from its inlet end, and bearing at its inner end against the outer end of the valve-bushing, said plug having a central guide-aperture extending therethrough, a sliding valve-piston in the valve-chamber, a valve-stem connected with said piston and sliding at its outer end in said hollow plug, and provided at its outer end with a lateral socket, a coiled actuating-spring surrounding the said valve-stem between the inner end of said plug and the said piston, and an actuating-lever pivoted to the casing and engaging with the socket in the outer end of the valve-stem.

816,261. Pneumatic Despatch Apparatus. Franklin S. Smith, Phila, Pa. Filed June 28, 1905. Seriol No. 267,404



*Claim.*1. A pneumatic despatch apparatus comprising a terminal having a discharge opening, a device which extends across the said opening and which device is normally in a closed position, a pivoted catch normally in engagement with the said device, and means integral with the said catch which extends therefrom into the interior or passageway of the said terminal, and a carrier provided with a head upon its end which is adapted to engage the said means to occasion disengagement of the catch from the said device to permit the latter to be opened by the impact of the said carrier.

816,262. Pneumatic Despatch Apparatus. Franklin S. Smith, Phila., Pa. Filed June 28, 1905. Serial No. 267,403.



Claim.—1. A pneumatic despatch apparatus, comprising a despatch tube, a terminal provided with a discharge opening, a device which extends across said opening and which normally is in closed position, means in engagement with the said device and supported independently thereof, which normally prevents the same from being opened, and a device connected with the said means, which device extends into the interior of said terminal in the path of a carrier passing therethrough, the said last mentioned device being adapted to occasion disengagement of the said means from the said first mentioned device to permit the same to be opened.

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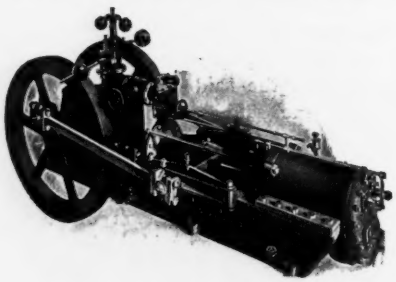

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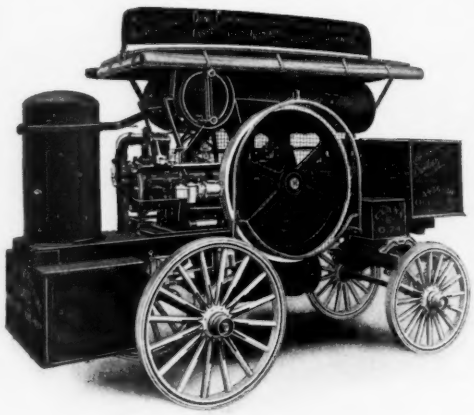

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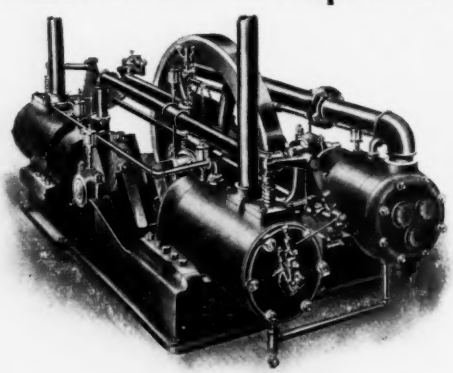

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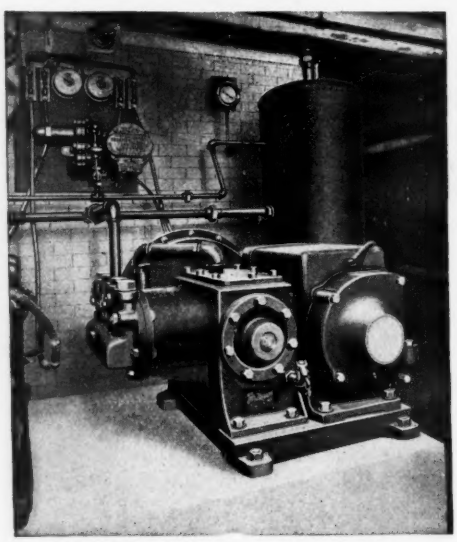

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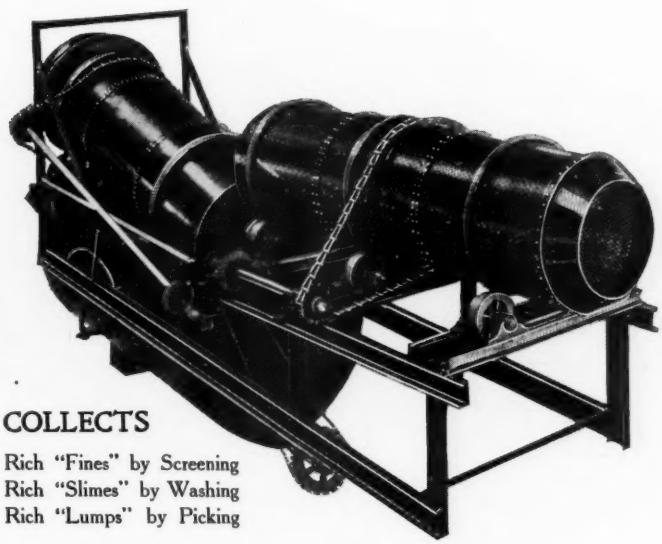

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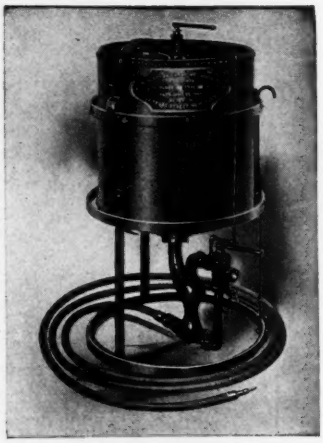

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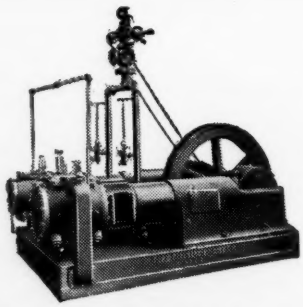

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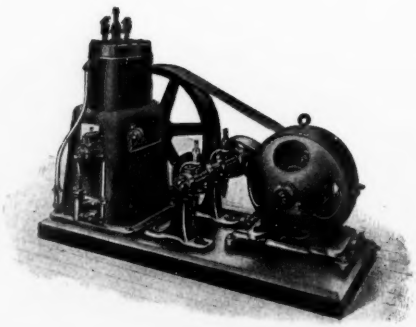

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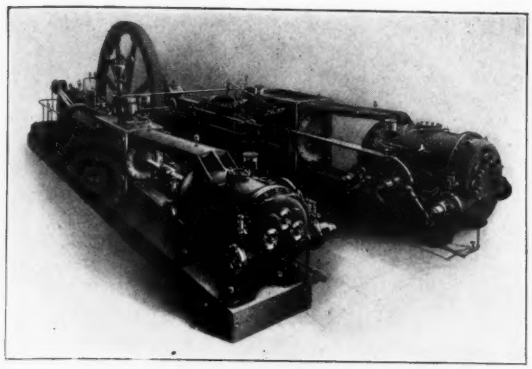

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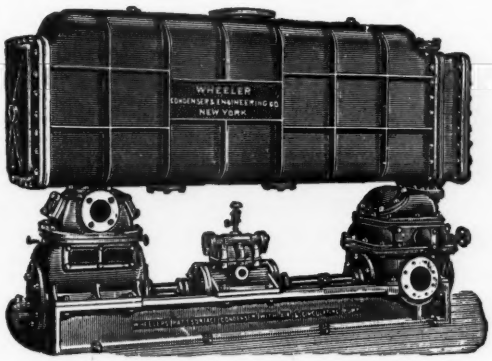

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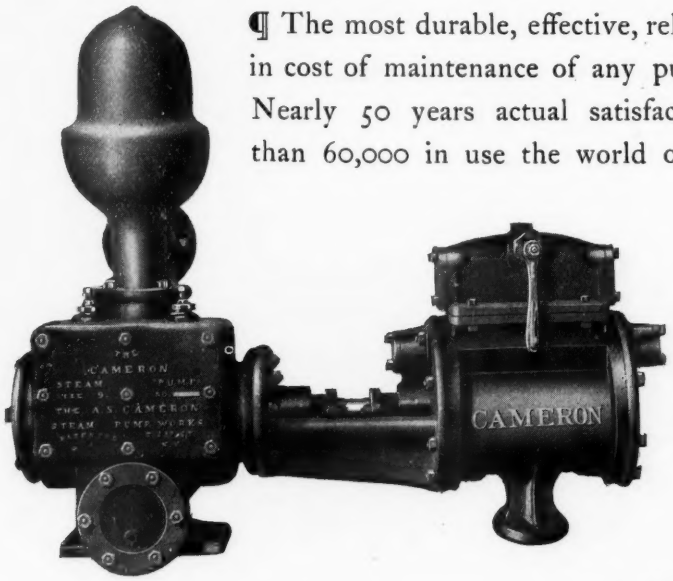

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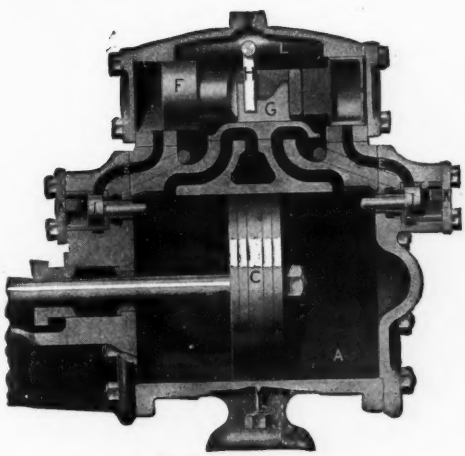

EXPLANATION

A is the steam cylinder; *C*, the piston; *L*, the steam chest; *F*, the chest plunger, the right hand end of which is shown in section; *G*, the slide valve; *H*, a lever, by means of which the steam-chest plunger *F* may be reversed by hand when expedient; *II* are reversing valves; *KK*, are the reversing valve chamber bonnets, and *EE* are exhaust ports leading from the ends of steam chest direct to the main exhaust and closed by the reversing valves *II*.

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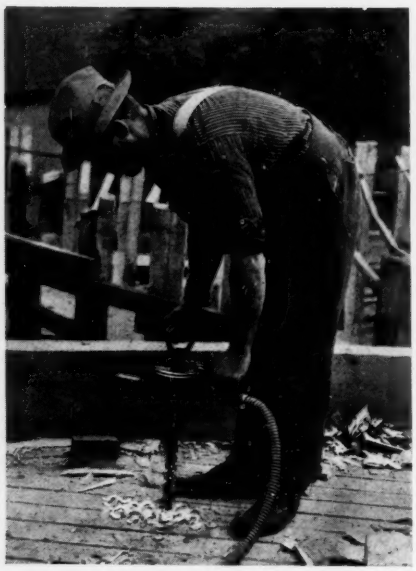

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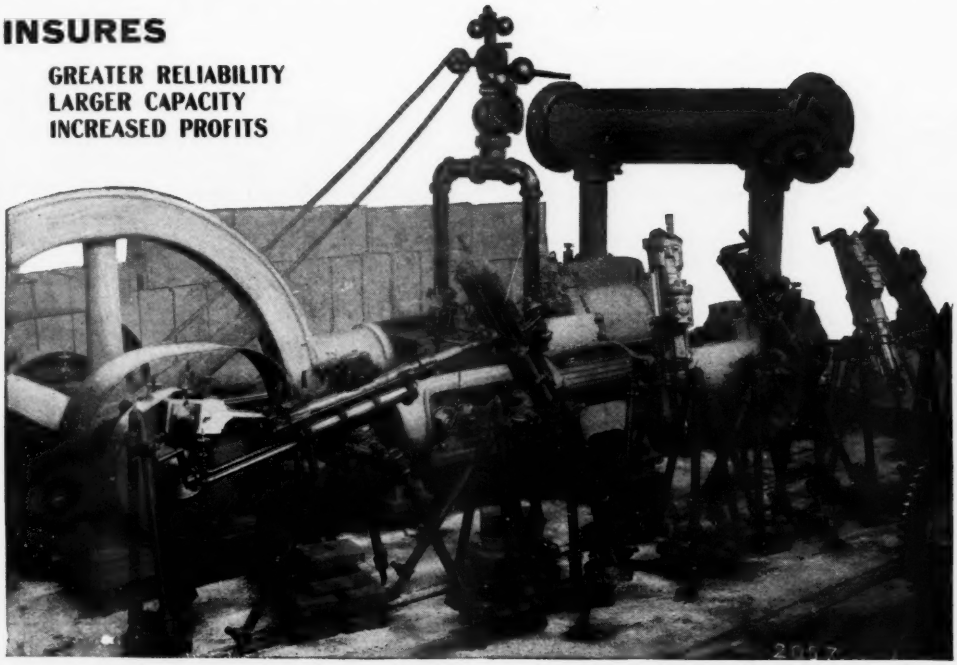

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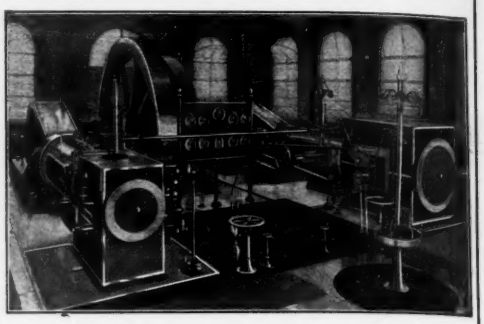

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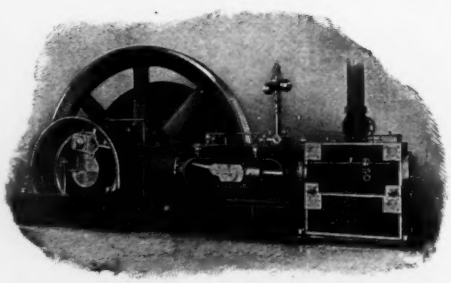

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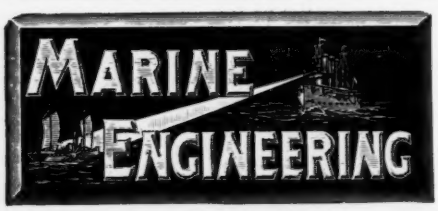

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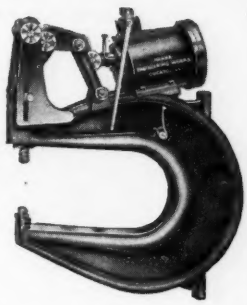

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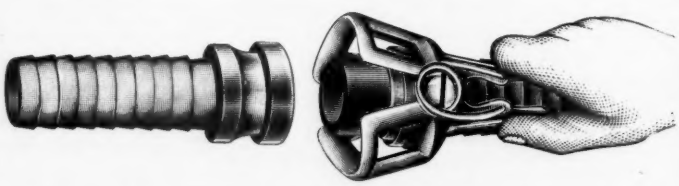

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